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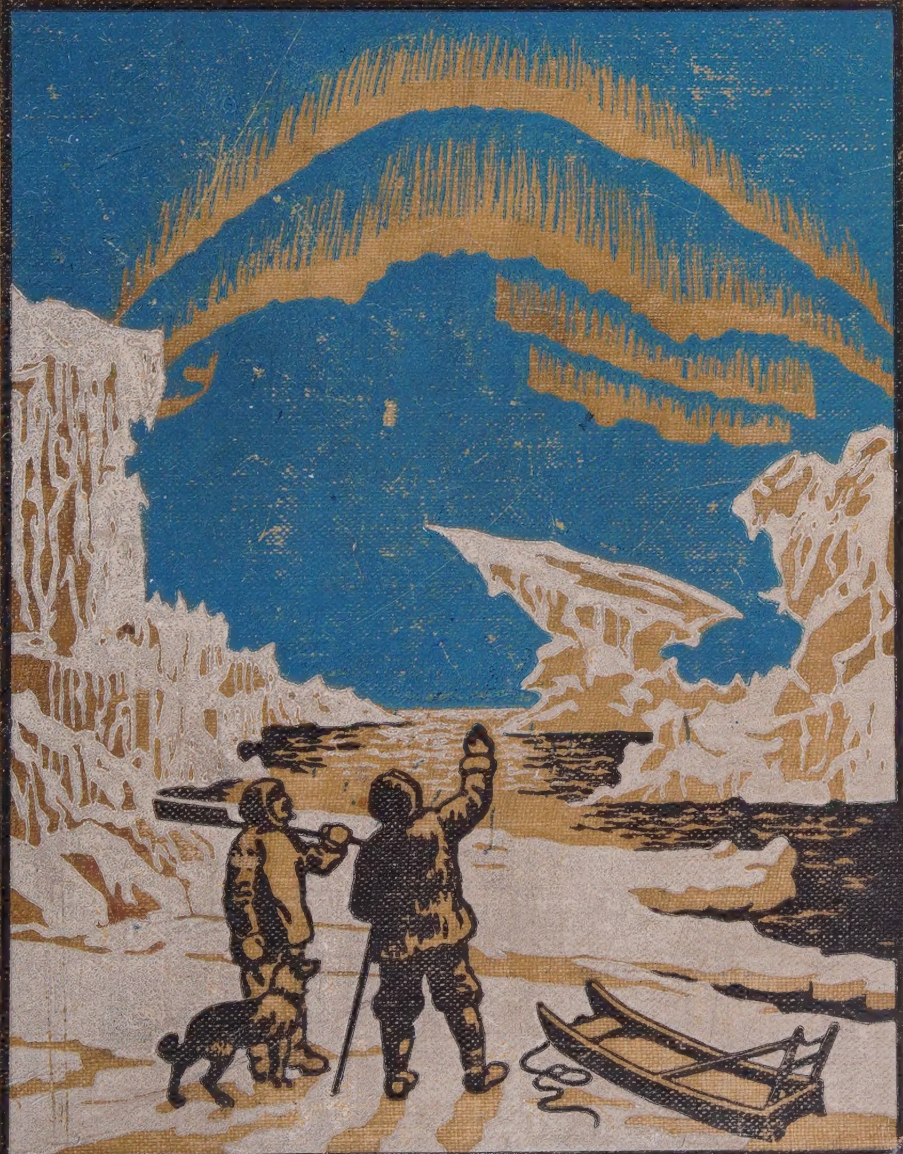

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PREFACE

IN the preparation of this volume the writer has received invaluable assistance from several well-known astronomers. His special thanks are due to Mr. J. E. Gore and Mr. E. W. Maunder for their kindness in reading over and correcting the proof-sheets, and for their useful suggestions; to Professor Percival Lowell for the two views of Mars and for the photograph of Saturn; and to Professor Max Wolf for the beautiful photographs of stars and nebulæ which are reproduced here by his kind permission.

Finally, the writer has to mention the kindness of Professor Schiaparelli for furnishing one of his classical drawings of Mars, and for permission to reproduce it in this book. Since that permission was granted, Professor Schiaparelli's death has bereft astronomy of an illustrious leader.

PUBLISHERS' NOTE

THE contents of this book have been taken from Mr. Hector Macpherson's larger book entitled "The Romance of Modern Astronomy," published at five shillings.

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THE ROMANCE OF MODERN ASTRONOMY

CHAPTER I

OUR PLACE IN THE UNIVERSE

SCIENCE is the study of Nature. By means of science we are enabled to understand the everyday things of life—the flowers, the hills, the stars—and the place which they occupy in Nature. Thus, botany is the study of the flowers and trees; geology is the study of the hills and rocks; while astronomy raises our thoughts to the star-spangled heavens.

Of all the sciences—and they are many and varied—astronomy is the most interesting and the most wonderful. Not only is it full of interest, but it is in many ways the most educative study which the human mind can pursue; for it enables us to understand the position which our world occupies in the Universe. By astronomy men were enabled to answer the question, "What is the Earth?"

In childhood we learn that "the Earth is round like an orange or a ball," but when we stand out in the open and look around us, the Earth seems more like a vast illimitable plain than a round globe. Long ago, in the childhood of the race, men believed our world to be a vast

illimitable plain, but reflective minds were not satisfied with this theory. They soon perceived that the Earth was not a plain. The Sun, it was observed, rose in the east every morning, and set in the west every evening, and it was obvious that it could not rise and set through the solid ground. The question presented itself to those early Chaldean and Greek students of Nature,—Where did the Sun go every night? Did it pass under the Earth? Such an idea was unthinkable to those early scientists. Was not the Earth solid and immovable, firmly fixed at the bottom of Creation? Accordingly some very remarkable theories were devised to explain how the Sun rose in the east in the morning, after having disappeared in the west the previous evening. Some of the ancients believed that the Sun fell into the sea at night and was quenched, and that the gods were busy all night making a new Sun to start the next morning in the east. But, as Sir Robert Ball remarks, "this was thought to be such a waste of good Suns that a more economic theory was afterwards proposed." This was that, as the Sun was falling into the ocean in the west, it was caught by the god Vulcan, who was waiting in his boat to prevent it falling into the sea. Having placed the orb of day in his boat, Vulcan rowed round by the north, where a great ocean was supposed to exist. Arriving in the east, he pitched the Sun into the sky with tremendous force, to commence another day's journey.

Theories such as these had influence for many years over the minds of men. Gradually, however, it became apparent that such ideas were absurd, and that the Sun must really go below the Earth. And here students of Nature asked—What is the Earth, and what supports it? Many grotesque theories were put forward. One

speculator thought that the Earth was held up by great pillars, which allowed the Sun to pass between them; another believed our world to be supported by enormous mythical animals. Some support, in the minds of the ancients, was absolutely necessary. The author of the Book of Job, however, had grasped the truth, for, writing of the power of the Creator, he says, "He hangeth the Earth upon nothing."

This is literally true; the Earth hangs upon nothing. Gradually the truth dawned that the Earth was a globe, not a vast plain—a view which was held by the great Greek philosopher, Aristotle, and became generally accepted. Aristotle thought that the Earth, a globe suspended in space, was the centre of the universe, round which the Sun, Moon, and stars revolved. By this time considerable progress had been made in the study of astronomy. The study of the stars had become a science of measurement, and it was soon apparent that the celestial bodies had not one motion round the Earth only, but a number of motions. For instance it was known that the Sun, Moon, and stars revolved round the Earth every twenty-four hours. But it soon became apparent, as observation progressed, that the Moon had another motion round the Earth once in a month; and that the Sun seemed to have also another motion, revolving round the Earth once in a year. Then attentive observation of the heavens disclosed the existence of another class of objects. The ordinary stars—"fixed stars" as they came to be called—revolved once in twenty-four hours. But they did not change their positions relative to each other. The star-groups or constellations remained unchanged. The early astronomers noted that there were five bright star-like objects, which, instead of remaining fixed in the sky,

moved in an irregular manner round the heavens, always keeping close to the path traversed by the Sun on its annual journey. These the early observers named "planets," which is Greek for "wanderers." It was soon recognised that there were five of these objects, each different from the other. There was Venus, the brightest of the wanderers, shining with a soft, gentle, steady light, named by the ancient Greeks after their goddess of love. They noticed that Venus never moved far from the Sun—that it was never to be seen shining on a really dark sky. It was also observed that Venus was sometimes visible as an evening star after sunset, and sometimes as a morning star before sunrise. Indeed it was long thought that the morning star and the evening star were separate bodies; but very early in astronomical history it was recognised that they were one and the same. The ancients recognised another bright object also visible as an evening and morning star, and keeping much closer to the Sun than Venus. They called the planet Mercury, "the messenger of the gods." But they also called it "the sparkling one," from its rapidly twinkling light. Another bright object, much brighter than Mercury, was also recognised —a great golden star, which, instead of keeping close to the Sun, swept majestically round the entire heavens. This they named Jupiter after their chief deity. Then they recognised a planet of reddish hue which at times waxed almost as bright as Jupiter, then rapidly waned. From its fiery colour they named this object Mars, after the god of war. Yet another planet, fainter than the rest—slow moving—of a dull yellowish light, creeping round the entire heavens once in about thirty years, was named Saturn, after the god of time.

Each of these planets had its own peculiarities of

motion, and partook also in the revolution of the entire heavens once in twenty-four hours. The problem before the ancient astronomers then was how to account for the motions of Sun, Moon, planets, and stars. Many and varied were the explanations put forward. Eudoxus, a Greek thinker who died about 355 B.C., was the author of an ingenious attempt to explain these motions by an elaborate theory known as that of the spheres. The Earth, he believed, was a globe firmly fixed at the centre of the universe. Each planet was fixed to a number of different spheres by the manipulation of which the elaborate motions resulted. Then at the extreme limit of the universe was a sphere to which all the stars proper were fixed.

Another theory was that of the astronomer Hipparchus, which was developed to its greatest extent by his successor, Ptolemy, of Alexandria, in Egypt. Like Eudoxus, Ptolemy believed that the Earth was firmly fixed as the centre of creation. But he did not accept the theory of spheres. He believed that the Sun, Moon, planets, and stars revolved round the Earth in the following order—the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the stars proper, which, as in the theory of Eudoxus, were supposed to be attached to the inside of a large sphere. But Ptolemy was not ignorant of the irregularities in the motions of the planets, of the fact that the planets did not move with uniform velocities. He was one of the most thoughtful of the ancient astronomers, and he knew that if a planet moved round the Earth in a uniform circular orbit, its velocity and direction would not change. Accordingly he devised a most complicated and ingenious theory —that the planets moved in circles, and that the centres of these circles revolved round the Earth in larger circles.

The smaller circles were called epicycles. As new irregularities came to be discovered, new epicycles had to be invented, until at last the theory became so difficult and cumbersome that few could understand it. Indeed it is recorded of a certain King of Spain that when his tutor was explaining to him the theory then generally accepted, he exclaimed in disgust that if he had been consulted at the Creation, he could have given some useful hints for simplifying the system of the Universe.

In spite of the intricacies and improbabilities of Ptolemy's theory, it was accepted for fourteen hundred years. It is true that some keen minds among the Greeks had come to the conclusion that there was a much simpler conception of the Universe; but they had not the courage to declare for a new theory, and it was left for Nicolaus Copernicus, a Polish clergyman, to propound the system which bears his name. Copernicus, after giving deep attention to the subject, came to the conclusion that it was much easier to believe that the Earth turned on its own axis, and so caused an apparent motion of Sun, Moon, planets, and stars, than to think that these objects all happened by some coincidence to go round our planet in exactly the same time. Copernicus also came to the conclusion that, instead of the Sun moving round the Earth once a year, and the planets also revolving round our world in complicated orbits, it was more reasonable to believe that the Earth and the other planets revolved round the Sun. This was the theory which Copernicus put forward. It had the merit of simplicity, but notwithstanding this fact, it was disbelieved, and its supporters were threatened with persecution. Nevertheless, men of science were driven to accept it, because they saw how

greatly its acceptance simplified the complicated motions of the planets. Tycho Brahe, the famous Danish astronomer, abandoned the idea that the planets revolved round our Earth, choosing to believe that they revolved round the Sun, which moved round our planet. The next step was to declare boldly that the theory of the Earth's motion explained more satisfactorily the motions of the celestial bodies. This step was taken by Bruno, Galileo, and Kepler. But it was taken at a great risk, and at a great sacrifice. Bruno was burned alive for holding this theory among others which the Roman Catholic Church had pronounced to be impious. Galileo had to suffer much persecution for his championship of the Copernican theory. Its opponents disliked Galileo most of all, because he brought forward unanswerable arguments in favour of the new system. Kepler, the least persecuted of the three, was destined still further to improve the theory by his famous "three laws." He showed that the Earth and the other planets, instead of revolving round the Sun in circular paths, moved in ellipses. He was enabled to explain many of the irregularities which Copernicus had to leave unsolved. Thus the labours of Copernicus, Galileo, and Kepler showed us beyond a doubt our true position in the universe—that the Earth is merely a planet in constant revolution round the Sun, a member of the Sun's system, and a companion planet of Mercury and Venus, Mars, Jupiter, and Saturn.

It was Sir Isaac Newton who demonstrated beyond doubt the truth of the system of Copernicus. Newton furnished mankind with a key to unlock the mysteries of the Solar System; he explained why the Earth and the other planets were constantly moving round the Sun,

and why they moved in elliptical orbits. It was in the year 1666, when Newton was a young man in his ancestral home near Grantham, in England, that his mind first lit on the grand idea of the law of gravitation—that every particle of matter in the universe attracts every other particle. The story goes that one day when Newton was sitting in his garden he saw an apple fall to the ground. Now, he knew why the apple fell—because it was heavy; in other words, because it was drawn to the Earth by the power of gravitation. And he was led to ask if the same force did not keep the Moon in its monthly orbit round the Earth, and prevent it flying off into space, and also keep the Earth and the other planets in their paths round the Sun. After twenty years' hard mathematical work, he was able to prove that the force which drew the apple to the ground held the Moon in its orbit; and that the Moon moved round the Earth, and the Earth and the other planets round the Sun, simply by virtue of the inherent power of gravity in these various bodies. For instance, the Earth attracts the Moon, and the Moon attracts the Earth; but the Earth is so much larger than the Moon that our satellite is compelled to revolve round our world. Similarly the Sun attracts the Earth, and the Earth attracts the Sun, but owing to the immense superiority of the Sun in size, the Earth, though having a natural tendency to move in a straight line, is compelled to move round the larger body.

Thus Copernicus showed us our Earth's position in the Solar System, and Newton showed us why we occupy that position. The result of the change in astronomical thought was that the Earth's inhabitants could no longer

consider themselves the chief objects of creation. Our world was brought down from the position of ruler and centre of the universe to the humble place of a small planet revolving round the Sun. As we shall find in the following chapters, this was but the first step in the change of opinion, for the researches of Sir William Herschel and later astronomers have proved that our planet is a mere grain of sand in the ocean of infinity. Astronomy enables us to understand the fact—though we but imperfectly realise it —that our Earth, which seems to us a great flat immovable plain, is in reality a globe about 8000 miles in diameter, turning on its own axis in twenty-four hours, and dashing onward in its orbit round the Sun at the rate of eighteen miles a second. We do not feel the motion of our planet, because we are carried along with it, and the atmosphere is also a component part of our globe. It is difficult to grasp the fact that our planet is moving onwards with so great a velocity, that each second of time finds us eighteen miles onward on our journey. Thus we see that astronomy, alone of the sciences, answers the question —What is our Earth, and what is its position in Nature ?

CHAPTER II

EFFECTS OF THE EARTH'S MOTIONS

THE motion of the Earth is the magic key which unlocks the door of the mysteries of the everyday phenomena of Nature. Day and night, the seasons, twilight, "the midnight Sun," the long polar night, all these phenomena are easily understood when we regard them in the light of the rotation of the Earth on its axis, the inclination of this axis, and the revolution of the Earth round the Sun.

To the first of these facts, the rotation of the Earth, we are indebted for the phenomenon of day and night. The Earth is constantly whirling round on its axis from west to east, and the result is the apparent motion of the heavenly bodies from east to west. By this motion of rotation we get the first and most obvious measure of time—the day which measures in length only a few minutes under twenty-four hours.

A good idea of the rapid rate at which the Earth is turning on its axis may be had by pointing a telescope to a star, and by noticing how swiftly the star passes out of the field of view. At sunrise and sunset, too, we notice plainly the difference made by a few minutes. Owing to the fact that the Earth has an atmosphere, daylight does not disappear whenever the Sun sinks below the horizon. The rays of the Sun still strike the upper regions of our atmosphere, and thus we have twilight and

the gradual darkening of the sky and disappearance of daylight.

The chief effect of the Earth's revolution round the Sun —an effect which affects the periods of light and darkness —is the change of the seasons, spring, summer, autumn, and winter. This ceaseless cycle, to which the Earth's inhabitants are so accustomed that they scarcely stop to ask themselves the why and wherefore, is due chiefly to one astronomical fact. The axis of the Earth—the imaginary line joining the north and south poles—is inclined to the orbit of our planet by about sixty-seven degrees. This explains the seasons and the differing lengths of day and night on the various parts of the Earth. Most of us have heard of such phenomena as the long polar night, the midnight Sun, &c., but few really understand that these phenomena are due to the same causes which give us our long periods of daylight in summer and of darkness in winter.

At the spring equinox, day and night are equal all over the world—at the poles and the equator. At this period both poles of the Earth are equally exposed to the solar rays. Neither is tilted towards the Sun more nor less than the other. But as the Earth moves gradually round, the northern hemisphere becomes more and more inclined towards the solar beams, while the southern hemisphere is more and more inclined away from the orb of day. Spring is giving place to summer. At the summer solstice the northern hemisphere is tilted towards the Sun at its greatest inclination while it is midwinter in the south. The days and nights were equal at the spring equinox; at the summer solstice the days are much longer than the nights in the northern hemisphere, the opposite being the case in the south. After the 21st of June the period

of darkness increases in the northern hemisphere and decreases in the southern, until on the 21st of September daylight and darkness are equal all over the globe. In its cycle of change the axis of the earth is again upright relative to the Sun. After the autumn equinox is past, the northern hemisphere tilts more and more away from the Sun, while the southern comes more and more into sunlight. The result is that by the 21st of December, when the winter solstice is reached, the northern hemisphere has a short period of daylight and a long period of darkness, while the reverse state of affairs takes place in the south. The northern hemisphere is tilted from the Sun at its greatest tilt. After the winter solstice the period of daylight increases in the northern hemisphere and decreases in the southern, until we come again to the 21st of March, when at the spring equinox day and night are equal all over the world.

In the early ages of the world, before astronomy had been developed, men did not understand this revolution of our dwelling-place round the Sun. They only knew, just as the unlearned know to-day, that at the winter solstice, in the middle of December, the Sun rose in the south-east, moved across the southern sky, rising to a low altitude above the horizon, and set in the south-west in the afternoon. We notice that after the solstice is past, the Sun rises a little earlier each morning and sets a little later each evening, that it rises farther east each morning, and sets farther west each evening, until on the 21st of March the orb of day rises exactly in the east and sets exactly in the west. Likewise we notice that as more and more is seen of the Sun, the Earth wakens out of its winter sleep. Trees begin to bud, grass to grow—in short, Nature revives. As one writer puts it: "The

melting of the ice and snow, the gradual reviving of brown soils, the flowing of sap through branches apparently lifeless, the mist of foliage beginning to enshroud every twig until the whole country is enveloped in a soft haze of palest green and red—all these are Nature's signs of spring."

Then as spring gradually passes into summer, the Sun rises every morning a little farther north, and sets every evening a little farther north, while every day it rises higher and higher in the sky. Then on the 21st of June, the "longest day," it rises north-east and sets north-west, and is about eighteen hours above the horizon. This is the period of longest daylight, because, as explained, the northern hemisphere is turned directly towards the Sun, but the period of greatest heat is about a month later in coming. If the Earth and the atmosphere could retain none of the heat which is showered down from the Sun, the period of greatest heat would exactly coincide with the summer solstice. However, the accumulation of heat retards the time of the greatest heat until about a month after the solstice—the end of July and beginning of August. Similarly the period of greatest cold is a month later than that of least sunlight—the end of January and the beginning of February.

Gradually summer passes into autumn. After the summer solstice is past, the Sun begins to rise later and later every morning and sets a little earlier every evening; and in addition, the orb of day does not rise so high in the heavens. This continues until the autumn equinox, when the sun rises due east and sets due west. In fact, day and night are equal all over the world, and the conditions are the same as those at the spring equinox. But there is one difference. The weather at

the spring equinox is generally cold and uncertain, while at the corresponding period in autumn it is summer-like and pleasant. This is due to the same cause which was previously mentioned, that after summer solstice the Earth continues to store up heat, while after winter the Earth is slow to absorb heat. In short, the autumn equinox generally takes place in summer-like weather. As an American astronomer expresses it: "Not until falling leaves begin to flutter about our feet, and grapes and apples ripen in orchard and vineyard, do we realise that autumn is really here—that everything is mellow and finished. Our hemisphere is turning yet farther away from that Sun on which all growth and development depend. When trees are a glory of red and yellow and russet brown, when corn stands in full shocks in fields, and day after day of warmth and sunshine follow through royal October—it seems impossible to believe that slowly and surely winter can be approaching. But soon chilly winds whistle through trees from which the bright leaves are almost gone; a thin skin of ice crystals shoots across wayside pools at evening, and speedily shivering winter is upon us. Just before Christmas this part of our Earth is tipped its farthest away from the Sun. Then for a few days the hours of darkness are at their longest. The sap has withdrawn far into the roots of the trees until the cold shall abate; leaden skies drop snowflakes, and earth sleeps under a mantle of white."

This description applies only to the temperate zones of the Earth. As we go northwards we approach the exaggerated aspects of the same phenomena—the midnight Sun and the long polar night. The cause of these phenomena is a source of difficulty to many, but it is quite easily understood with a little thought.

At midnight in the end of June, in Scotland there is very little darkness. The sky never grows actually dark. We seem to see the glow of the Sun almost up to midnight after it sinks in the north-west. As we go farther north we see more and more of the Sun. We follow it farther and farther until it just goes below the horizon, and no more. Still farther north it skirts the horizon, and is visible all night at the sixty-sixth parallel of latitude. Beyond this the Sun does not disappear at all in summer, and there are six months of daylight.

The phenomenon of the midnight Sun draws many to the northern parts of Sweden, Norway, and Russia, where for a few days at the summer solstice the sun merely skirts the northern horizon. A good description of the midnight Sun is given by Paul du Chaillu in his account of his travels in Scandinavia: "The brilliancy of the splendid orb varies in intensity, like that of sunset and sunrise, according to the state of moisture of the atmosphere. One day it will be of a deep-red colour, tingeing everything with a roseate hue and producing a drowsy effect. There are times when the changes in the colour between the sunset and the sunrise might be compared to the variations of a charcoal fire, now burning with a fierce red glow, then fading away and rekindling with greater brightness.

"There are days when the Sun has a pale, whitish appearance, and when even it can be looked at for six or seven hours before midnight. As this hour approaches, the Sun becomes less glowing, gradually changing into more brilliant shades as it dips towards the lowest point of its course. Its motion is very slow, and for quite a while it apparently follows the line of the horizon, during

which there seems to be a pause, as when the Sun reaches noon. This is midnight. For a few minutes the glow of sunset mingles with that of sunrise, and one cannot tell which prevails; but soon the light becomes slowly and gradually more brilliant, announcing the birth of another day. . . . How beautiful was the midnight. How red and gorgeous was the Sun! How drowsy was the landscape; Nature seemed asleep in the midst of sunshine; crystal dewdrops glittered like precious stones as they hung from the blades of grass, the petals of wild flowers, and the leaves of the birch trees."

Farther north the Sun is constantly visible and the north pole has six months' continuous light. But there is another side to the picture. For six months there is continuous night, and even in the north of Sweden, Norway, and Russia there are days in midwinter when the Sun does not rise, just as in summer there are days when it does not set. Du Chaillu, after describing the midnight sun, has the following remarks on the winter in the same region, which is worth quoting: "The grass turns yellow; the leaves change their colour and wither and fall; the swallows and other migrating birds fly towards the south; twilight comes once more; the stars, one by one, make their appearance, shining brightly in the pale-blue sky; the Moon shows itself again as the queen of night, and lights and cheers the long and dark days of the Scandinavian winter. The time comes at last when the Sun disappears entirely from sight; the heavens appear in a blaze of light and glory, and the stars and the Moon pale before the Aurora Borealis."

Such are the various phenomena resulting from the fact that the axis of the Earth is inclined to the plane, or level, of its orbit. Were the axis upright, there

THE AURORA BOREALIS

The aurora, which illuminates the long winter nights of the Far North, is one of the most wonderful sights in the skies. Sometimes seen in our latitudes, it is seen to most advantage in the Far North. Of an undoubted electrical origin, it varies in harmony with the sun-spot period about every eleven years.

would be no seasons, no spring-time, no summer, no autumn, no winter season; there would be no midnight Sun and no long polar night. In fact the continuous state of affairs would be an everlasting springtime without the charm of our earthly spring. This seems to be the state of affairs on Jupiter, where the axis is nearly perpendicular to the planet's orbit.

Another fact has also something to do with the seasons, though only in a modified degree. As the orbit of the Earth is not a perfect circle, but an ellipse, the Earth is at one point of its orbit nearer to the Sun than at the other. The Earth is nearer to the Sun by three million miles in our winter than in our summer. At first this seems a paradox, that the time of closest approach to the orb of day is the time of greatest cold. A little consideration, however, soon disposes of the difficulty. In the northern hemisphere the decreased distance of the Sun modifies the severities of winter, while its increased distance mitigates the heat of summer.

In the southern hemisphere, on the other hand, the time of greatest heat takes place when the Sun is nearest, and the time of greatest cold when the Sun is at its greatest distance. Thus the climate in the northern hemisphere is rendered more equable than that in the south.

Thus we understand that it is owing to the inclination of the axis of the Earth that the Sun's apparent path in the heavens, *the ecliptic*, is tilted, and that the Sun rises so much higher in the sky in summer than in winter. A similar line of reasoning applies to our satellite the Moon. There is much less moonlight in summer than in winter. At a first consideration it seems as if this was owing to increased daylight, the

moonlight not being required, and consequently not noticed; but such is not the case. There is really less moonlight in summer than in winter. This arises from the fact that before the Moon can be "full" and shining with complete radiance, it must be "in opposition" to the Sun, that is, situated in the diametrically opposite portion of the sky. In winter the Sun is traversing the lower zodiacal constellations, and as a result the Moon at the full phase passes through the higher. The full Moon at midwinter has the same situation as the Sun at midsummer. Thus in winter we get more moonlight than sunlight. In summer the conditions are reversed. The Sun is in the higher constellations; consequently the full Moon at midsummer occupies the place of the Sun at midwinter, and thus there is more sunlight than moonlight. Instead of shining from on high with silvery radiance, the Moon, in summer, creeps through the lower constellations, gleaming with a golden hue, which harmonises with the period of summer-time. As Mr. Maunder puts it: "The evasive Moon recognises that the season belongs by right to her more powerful brother, and timidly skirts the south as if anxious to escape notice."

The apparent yearly motion of the Sun is due to two causes—the motion of the Earth and the inclination of the Earth's axis. The apparent motion of the Sun is not itself visible, but we can trace it in an apparent drift of the stars into the sunlight. The stars, as a result of the Sun's apparent motion amongst them, set four minutes earlier each night. In a fortnight or a month this makes an appreciable difference in the aspect of the sky. For instance, at 10 P.M. in the beginning of January, Orion and the winter constellations occupy

prominent positions in the southern heavens. At the same hour a month later they have moved considerably to the west, while in March they are beginning to pass over towards the western horizon. By watching these changes with care and attention, the ancient astronomers were enabled with tolerable accuracy to trace the apparent pathway of the Sun among the stars.

A word may be said here as to the difference of the day measured by the Sun—"the solar day"—and that measured by the stars—"the sidereal day." Sidereal time is the exact time required for one star to move from the meridian round to the meridian again, in fact it is the exact time required by the Earth to rotate on its axis. But the sidereal day is not the ordinary day. Were the Earth standing still it would be so. But our planet not only whirls round on its axis; it is also moving round the Sun. As a consequence of the motion of the Earth, which gives rise to an apparent motion of the Sun, the Sun appears to come to the meridian four minutes later each day if we reckon time by the sidereal clock. In other words, the day measured by the Sun is four minutes longer than the day measured by the stars, and the difference amounts to exactly one day in each year. Now sidereal time is in reality the only true measurement of the day, because it is the exact time of the rotation of the Earth's axis. But it is impossible to measure our ordinary time by this method. Professor Todd puts it very clearly in the following words: "Sidereal noon comes at all hours of the day and night during the progress of the year. Plainly, then, sidereal time is not a fit standard for regulating the affairs of ordinary life, for while it would answer for a fortnight or so, the displacement of four

minutes daily would in six months have all the world breakfasting after sunset, staying awake all through the night, and going to bed in the middle of the forenoon." The difficulty cannot be exactly solved by taking the solar day instead of the sidereal, for, as Professor Todd says, "Begin on any day of the year and observe the Sun's transit of the meridian as you did that of a star. The instant when the sun's centre is on the meridian is known as apparent noon. If you repeat the observation every day for a year and compare the intervals between successive transits, you will find them varying in length by many seconds, because they are all apparent solar days; they will not all be equal as in the case of the star. By taking the average of all the intervals between the Sun's transit—that is, the mean of all the apparent solar days in the course of the year—an invariable standard is obtained like that from the stars themselves." Thus we have the mean solar day by which all the clocks and watches in everyday life are regulated.

CHAPTER III

THE ORB OF NIGHT

IN early times, as was seen in the previous chapter, men believed that the Earth was the centre of the Universe, and round it all the orbs of heaven revolved. To-day we know that only one celestial body owns allegiance to the Earth. That orb is our satellite, the Moon, which goes round our world once in about twenty-seven days. The Moon's revolution round the Earth from east to west in a little over a day is only apparent, the result of our planet's rotation on its axis, but its motion from west to east is real.

We owe much to the Moon. To it we owe the glorious silvery light which our satellite sheds on us. As Flammarion has said : "It is the delightful hour when all Nature pauses in the tranquil calm of the silent night. The Sun has cast his farewell beams upon the weary Earth. All sound is hushed. And soon the stars will shine out one by one on the bosom of the sombre firmament. Opposite to the sunset in the east the full Moon rises slowly, as it were, calling our thoughts towards the mysteries of Eternity, while her lamp light spreads over space like a dew from heaven." Not only is the moonlight useful, it is exquisitely beautiful.

The most casual observer of the heavens cannot fail to notice that as the Moon moves eastwards in the heavens its form changes. When we first see the new Moon in the western sky above the sunset, it is a slender crescent

of silvery light. Night after night it grows in size until about five days after we first see it it is half full. It has reached its "First Quarter." It continues to grow for about another week, until one evening it rises just as the Sun sets, and reaches the meridian, the point due south, about midnight; while it is fully illuminated and its round disc sheds over our world that inimitable light known as moonlight. Then slowly its size decreases. It rises later and later, and grows smaller and smaller, until when it reaches its "Last Quarter" it is only to be seen in the morning hours. And then it draws closer to the Sun until its thin little crescent is lost in the sunrise, to emerge some days from the sunset as "New Moon."

Those who do not give the matter sufficient consideration believe that the Moon actually changes its shape as it moves round the Earth. Indeed it is recorded of a novelist that he wrote of a star shining between the horns of the crescent Moon; the poet Coleridge makes the same mistake in the "Ancient Mariner." A little consideration, however, will show that there is no real change of shape. Like our own world, the Moon is a dark globe, and it only shines by the reflected light of the Sun. Therefore, only one half of the globe is illuminated at once. Just before the crescent of the new Moon appears, when the Moon is between the Earth and the Sun, the dark side of the Moon is turned to the Earth and we do not see it. At First Quarter we only see one half of our satellite illuminated. As the Moon moves eastward we see more and more of the illuminated surface, until at full Moon the orb is at the other side of the Earth from the Sun, and we see it fully illuminated. Then as it draws closer to the Sun we see less and less of the illuminated surface, until it becomes once again invisible.

What is the distance of the Moon? That is the first question which presents itself to the beginner in astronomy. The distance varies slightly from time to time as its orbit round our Earth is not circular, but slightly elliptical or oval; but the average distance is 238,000 miles. It is near to us when compared to the other celestial bodies. But the question at once occurs, How is it possible to measure the distance? We do not require to reach the Moon in order to measure its distance, any more than we require to ascend a mountain to measure its height. In these measurements we proceed on the principles of land-surveying.

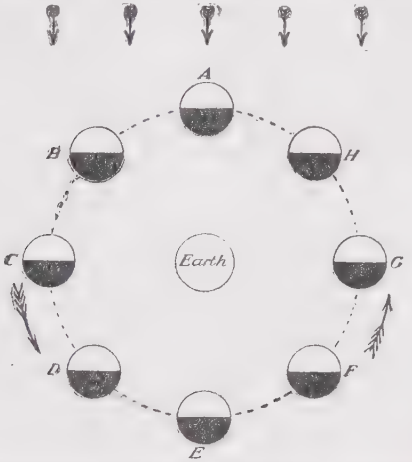
The principles of land-surveying depend on the measurement of angles. As Professor Comstock puts it: "The instruments used by astronomers for the measurement of angles are usually provided with a telescope, which may be pointed at different objects, and with a scale to measure the angle between lines drawn from the instrument to two different objects, such as two church steeples, or the Sun and Moon, and this is usually called the angle between the object. By measuring angles in this way it is possible to determine the distance to an inaccessible point."

An observer wishes to measure the distance of a flagstaff at the other side of a river which he is unable to cross. Accordingly he chooses two points on his own side of the river, from which to make observations. The line joining these points he calls the base-line, the length of which he ascertains. From either point he measures the angle "subtended" by the opposite sides at these points. Having measured the angles, he now determines the elements of the triangle, and by means of trigonometry he knows the distance across the river to the flagstaff without having ever crossed it.

Similarly in regard to the distance of the Moon. One astronomer located, say, at Greenwich or Edinburgh, measures the Moon's position amid the neighbouring stars. Another at Cape Town or Sydney, measures its position seen from that place. The difference of position of the Moon at the two stations—"the parallax" as it is called—is then measured and the distance of the Moon is found to be 238,000 miles, a great distance indeed, when compared with our terrestrial standards, but very small in the eyes of the astronomer. A railway train travelling night and day at the rate of sixty miles an hour would reach the Moon in six months. The Moon, as it were, is our own particular possession. It illuminates our nights; it raises the tides in our oceans; it revolves around our world; it is the nearest of the celestial bodies, the only one whose distance is to be measured in thousands of miles. As has been remarked, it is a detached continent, and, as we shall see later, this is probably true in more senses than one. As a result of its proximity, we know more of the Moon than of any other celestial body. Indeed, we know its geography, or rather "selenography," better than we know that of the Earth. We are close enough to the Moon to see its surface spread out before us in a bird's-eye view. By trigonometrical measurements we can measure the heights of the lunar mountains. We have seen the poles of the Moon.

This, however, only applies to one hemisphere of the Moon. The other side has never been seen by human eye. The explanation is that the Moon, instead of turning on its axis in twenty-four hours like the Earth, requires for its rotation on its axis the exact period of its revolution. Thus the Moon always turns the same

face to the Earth. Owing, however, to the fact that the Moon's velocity in its orbit varies, the orbit being slightly elliptical, while the rate of rotation remains the same, we sometimes catch a glimpse of the other



Various positions and illumination of the Moon by the Sun during her revolution around the Earth.

The corresponding positions as viewed from the Earth, showing the consequent phases.

FIG. 1.—Orbit and Phases of the Moon.

hemisphere. This is known as the "libration" of the Moon.

So far, the Moon has been viewed as an object and as the satellite of the Earth. It must now be considered as a world. When we look at the Moon, even casually,

we cannot but notice that the bright disc is diversified. Most people see in the full Moon a likeness to a human face, and this is called "the Man in the Moon." Even in the crescent Moon and half Moon it is obvious that there are dark markings. In early times no one knew what these markings signified. Some of the ancients thought that the Moon was a great mirror in which we saw the Earth's markings reflected, while others held the correct view, namely, that the diverse markings represented the actual configuration of the Moon's surface. Soon after the invention of the telescope, Galileo turned his little instrument on the Moon. He was thus enabled to show that our satellite was diversified by mountains and valleys, and great grey stretches, which he believed to be seas. Later astronomers, following in this belief, gave these grey stretches names. Thus we have on the Moon the "Mare Serenitatis"—"Sea of Serenity"; the "Mare Tranquillitatis"—"Sea of Tranquillity" &c. It was obvious as astronomical research progressed that these stretches were not seas, but great plains. It is now known that there are no seas on the Moon, but the old names are retained for convenience. It is quite possible that these plains are ocean beds, from which the water has long since disappeared.

Like the Earth, the Moon is diversified by all kinds of formations. There are mountain ranges, isolated mountains, and volcanic craters. The mountain ranges have been called after mountains on the Earth. Thus there are on the Moon, the Alps, the Apennines, and the Carpathians. The highest mountains on its surface, so far as known, are the Doerfel and Leibnitz mountains, about 25,264 feet high. As Flammarion remarks: "Relatively to its proportions, the satellite is much more

mountainous than the planet, and the mountainous giants are much more numerous than here. If we have peaks like the highest of the Himalayas, and of the whole Earth, whose elevation of 29,000 feet is equivalent to $\frac{1}{1140}$ the diameter of our globe, there are peaks on the Moon of 25,264 feet, those of Doerfel and Leibnitz, the height of which is equivalent to $\frac{1}{470}$ the lunar diameter." It will thus be seen that the peaks of the Moon are much higher in proportion to its size than those of our own world. The surface, too, is much more rugged and mountainous than that of the Earth. There has been much volcanic activity on the Earth, but there has been much more on the Moon. Indeed on it the volcanic crater is the commonest type of formation. The smallest telescope will reveal the largest of these wonderful formations. The craters are named after eminent astronomers, men of science, and philosophers, and among the more prominent are Tycho, Copernicus, Plato, and Archimedes. Some of these craters are enormous. A large type of formations somewhat similar to the craters are the walled plains. Some of these are actually 150 miles across; and they are, as their name implies, encircled by ramparts of considerable breadth, which in some cases rise to a height of about 12,000 feet above the enclosed plains. In some cases, too, the floors of these walled plains are diversified by the presence of minute craters and mountains.

Another curious formation peculiar to the Moon is that known as the "rills." Of these rills the late Mr. Elger, a well-known English observer of the Moon, writes: "They often extend for hundreds of miles in approximately straight lines over portions of the Moon's surface, frequently traversing in their course ridges,

craters, and even more formidable obstacles, without any apparent check or interruption. Their length ranges from ten or twelve to three hundred miles or more, their breadth from less than half a mile to more than two, and their depth from a hundred to four hundred yards." On the Earth we have nothing like them—great yawning chasms running for miles over craters, mountains, and plains.

The study of the Moon's surface is now a distinct branch of astronomy. To it many distinguished astronomers, such as Mädler and Schmidt, have given the best part of their lives. Schmidt, a notable German astronomer, commenced his observations of the Moon, with a view to constructing a chart, at the age of fourteen. He just lived to finish his great work, about forty years later. In recent years photography has been largely used in the study of the Moon, and in the able hands of Professor W. H. Pickering of Harvard, U.S.A., much has been learned in this way concerning the lunar surface. To the casual observer the first quarter is the most satisfactory phase. The full Moon is a disappointing object in the telescope. The Sun is shining direct on its surface; it is noon on the part of our satellite which we are observing, and the mountains and crater walls cast no shadows, just as on our own world the shadows are shortest at noon. At the first quarter, on the other hand, it is positively fascinating to watch the dividing line between light and darkness—the terminator, as it is called in astronomical language—and to note the sunrise on the various mountain peaks. It is about the time of the first quarter that we see the surface of the Moon at its best. It is at this time that the Moon is most useful to the astronomer, just as the full phase

From a Photograph taken at the Paris Observatory by M. P. Puiseux.

THE MOON

This is a photograph taken near the first quarter, but, of course, inverted, as in astronomical telescopes. The craters and mountain ranges are well shown.

is the most useful to the ordinary inhabitant of the Earth.

We have briefly described the surface of the Moon—its grey plains, its mountains, its craters, and rills. What do we learn from a study of these features? Is our satellite a world like the Earth?

It is not a world like the Earth. The first great difference is obvious to the most casual observer. The Moon's surface is always to be seen clearly defined without a trace of haziness. There is no atmosphere. Practically it is an airless globe. Could we see the Earth from some point in space we should sometimes see it clearly defined when the atmosphere was clear, but at times we should see it enshrouded in cloud. But we never see clouds on the Moon; it is airless. Not only is there no air. There is no water. The Moon's surface is, to all intents and purposes, changeless, airless, and lifeless. Without air there can be no water, without water, no life. There is no vegetation on the grey plains, no heathery moors, no pine-covered mountains, merely a succession of arid, it may be crumbling rocks. As Professor W. H. Pickering has pointed out, there is probably a certain amount of change, almost imperceptible. At the bottoms of the craters there seem to be some last relics of the Moon's atmosphere, and perhaps the remnants of a lunar vegetation, perhaps a feeble little eruption almost unnoticeable, but that is all. The Moon is a dead world, and it is exceedingly unlikely—indeed we may say it is impossible —that any but the very lowest forms of fungus-life could live on it for one hour. The want of air, as already said, means want of water; it also means violent change of temperature. The Moon's day is equal to twenty-nine and a half of our days in length. For half of this

period the Sun beats down on the surface of the Moon. There is nothing to temper the broiling heat. The surface is scorched and baked. Then the Sun sets, and the long night comes on. There is no air to retain the heat; it escapes into space, and the lunar surface is frozen by an intense cold, a cold more terrible than we can conceive.

Could we visit the Moon, what an extraordinary world we should find it to be! There is no atmosphere, and as a consequence of this the stars are visible in all their glory when the Sun is shining. On Earth the stars are invisible in the daytime because the sunbeams are dispersed in our atmosphere, and this "veil of sunbeams" hides the stars from view. But on the Moon there is no veil of sunbeams. The Sun is seen with all his appendages which on Earth are invisible except during total eclipses —his red flames and his corona. Slowly, very slowly, the Sun creeps across the black sky, until in fourteen earthly days he sinks below the horizon to illuminate the opposite hemisphere.

From the side of the Moon facing earthwards, there is seen hanging, fixed and motionless in the sky, an enormous orb, a gigantic moon shedding its rays continually on the surface of our satellite. Sun and stars may pass behind it, but this orb hangs fixed in its place in the heavens. This body, which appears from thirteen to fourteen times as large as the Moon seems to us, is our dwelling-place, the Earth. The magnificence of the "Earthlight" which our world sheds on the surface of the Moon, is difficult to imagine. From the Moon's surface our world is to be seen in all its aspects—blue skies, clouded skies, haze, and mist. Sometimes it is "full Earth," sometimes "new Earth," sometimes the quarters, continually spinning on its axis, and exhibiting

every part of its surface in turn. Of the power of this reflected light we may get an idea from a consideration of a common phenomenon seen from the Earth. Most people have seen the "old Moon in the new Moon's arms"—the crescent Moon completed by a darker portion which shines with a dull light. This is the portion of our satellite illuminated by earthshine and reflecting back to us the light of our own planet. Thus we see the light of our own world reflected back to us from the heavens.

The chief features of the silver orb of night have been described. It has been seen to be a globe, similar in some respects to the Earth, but vastly different in its physical condition — a globe uninhabited and uninhabitable, a succession of rugged, jagged rocks, great grey barren plains, and volcanic regions. We have now completed our survey of the Earth's vicinity, and have passed the first sign-post on a journey through the depths of space.

CHAPTER IV

THE FOUNTAIN OF LIGHT

SCHIAPARELLI has called the Sun "the most magnificent work of the Almighty," and so far as our world is concerned the orb of day certainly merits the title. Without the Sun, life on the Earth would be impossible; without the Sun, indeed, there would be no Earth. Yet, so accustomed are Earth's inhabitants to the day star, that day after day we experience light and heat, year after year we enjoy the summer season, and do not stop to consider the source of these marvels. It is well to remember, occasionally at least, that the Sun is all in all to our planet.

There are many marvels in connection with the Sun, but perhaps nothing is more astounding than its vast distance and enormous size. The distance of the Sun from the Earth, as ascertained by methods similar to those used to measure the distance of the Moon—mentioned in the previous chapter—is, roughly speaking, ninety-three millions of miles. The Earth's orbit is not exactly circular, it is slightly elliptical, and as a result the Sun's distance varies from ninety-one to ninety-four millions of miles. It is easy to write out the figures representing ninety-three millions of miles (93,000,000), but it is not so easy to realise the enormous distance which these figures represent. Sir Robert Ball has given an excellent illustration as follows: "How long will the

clock have to tick before it has made as many ticks as there are miles between the Earth and the Sun? Every minute the clock, of course, makes sixty ticks, and in twenty-four hours the total number will reach 86,400. By dividing this into 93,000,000 you will find that more than 1076 days, or nearly three years, will be required for the clock to perform the task."

There is another vivid way of illustrating the Sun's distance. A tour round the world, involving a journey of 24,000 miles, can be accomplished in sixty days. Before a traveller could cover 93,000,000 miles he would require to accomplish about 4000 of these journeys. He would be six hundred years old when he arrived, even supposing him to start on his journey as an infant. Take another illustration. If it were possible to travel to the Sun in a railway train, night and day without stopping, at the uniform rate of forty miles an hour, it would require no less than 265 years to reach its destination. If the train had started in the time of Cromwell, it would not yet have reached its destination.

No less astounding than the Sun's distance is its size. The diameter of the solar globe is 866,000 miles. No fewer than 109 globes of the size of the Earth would be necessary to stretch from the one side of the Sun to the other. Properly to estimate its size in comparison with that of the Earth, we must consider its volume. The volume of the Sun is one and a quarter millions of times greater than the volume of the Earth. If all the planets, satellites, and cometary and meteoric bodies in the solar system were rolled into one globe, it would take no fewer than 750 of such globes to equal the volume of the Sun. Professor Gregory gives the following unique illustration of the Sun's size: "If we had a contract

to build up this stupendous bulk, and were to deliver a load of the same size as the Earth every hour, the order could be completed working night and day for 150 years."

We have seen by how much the Sun exceeds the Earth in volume. In weight, however, the Sun exceeds our world only 330,000 times. This proves that the density of our world is about four times that of the Sun. The reason of this is that while our world is a solid globe, the Sun, as we all know, is a great ball of gas, incandescent, glowing with an inconceivable heat. We all feel that the Sun is very hot; even on our planet it sometimes shines so brightly as to make us uncomfortable. What, then, must be its actual heat if it can be oppressive at a distance of 93,000,000 miles? Perhaps the best illustration on this point was given by Professor Young, the well-known American astronomer: "If we could build up a solid column of ice from the Earth to the Sun two miles and a quarter in diameter, spanning the inconceivable abyss of 93,000,000 miles, and if the Sun should concentrate his power upon it, it would dissolve and melt, not in an hour, not in a minute, but in a single second; one swing of the pendulum and it would be water, seven more and it would be dissipated in vapour." The estimated temperature of the solar surface is no less than 18,000 degrees Fahrenheit. The heat emitted by the Sun in each second, according to one of the most distinguished of modern astronomers, is equal to that which would result from the combustion of eleven quadrillions, six hundred thousand millions of tons of coal burning at the same time. This does not help us to realise the heat of the Sun. It helps us rather to realise how far the whole subject transcends our comprehension. How is this enormous heat maintained? It has been calculated

that if the Sun were composed of coal it would burn out in six thousand years. But the orb of day has lasted much longer, and seems to be in its prime. The most probable explanation of the source of the Sun's heat is that the solar globe is contracting. This contraction generates heat, which it has been calculated will keep the Sun at a high temperature for ten million years! It is also possible that the element radium may have something to do with the maintenance of the solar heat, but here we are in the region of speculation.

Equally astounding is the brightness of the Sun. The "intensity of sunlight," as it is called, at the surface has been estimated at 190,000 times that of a candle flame, 146 times that of a calcium light, and three and two-fifths that of an electric arc. Then in regard to the brightness of the sun, it is estimated that the total light is equal to 1,575,000,000,000,000,000,000 millions of wax candles. This unthinkable row of figures can assist us in realising, as it were, the incomprehensibleness of the brilliance of the day star. In reference to the light and heat of the Sun, it is well to bear in mind that the Earth and its inhabitants receive only a very small portion. It has been calculated that if the Sun were expending, instead of energy, money at the rate of £18,000,000,000 a year, the earth's annuity would be only £9.

Owing to the dazzling brightness of the Sun, it is impossible to observe it in a telescope without the aid of a dark glass. When we first observe the Sun through the telescope, we behold a disc of yellow light. If we scan the disc carefully we shall, in all probability, notice one or two minute markings. These are the sunspots. These spots are not permanent

features of the Sun, like the mountains and craters of the Moon. They are merely temporary markings. Sometimes, indeed, they disappear in a day. An astronomer looks at a sunspot carefully one day, and makes a drawing of it. Next day he looks for it again, and finds that it has vanished or completely changed its form.

Now what are these sunspots? They were a mystery to the early astronomers who first discovered them—Galileo and Scheiner. Indeed, the discovery of these spots came on the men of science of the day with a shock of surprise. It was thought that the Sun was too "pure" to have "defects" on its surface, and accordingly the astronomers who first announced that they had seen spots on the Sun, were openly disbelieved. However, the spots were soon proved beyond all doubt to be really features of the disc of the Sun. Observation with moderate-sized telescopes, and even with small instruments, reveals a very remarkable fact concerning these spots; they are rents in the glowing atmosphere of the Sun. Another remarkable fact concerning sunspots is that they are not uniformly dark. The black central portion—the umbra, as it is called—is surrounded by a grey portion—the penumbra. These are supposed to be not really black and grey, but merely dark in comparison with the brilliant envelope of the Sun—the "photosphere," or "light-sphere," as it is called. Spots are supposed to be vast cavities in the glowing envelope. They vary greatly as to size. Sometimes a spot is so large as to be visible to the unaided eye. One famous spot was seen in February 1892. Its length was no less than 92,000 miles, and its breadth was 62,000 miles. A number of small spots were connected with the large one,

and the length of the group was 162,000 miles, the breadth being 75,000 miles. The spot group had an area of 3500 million square miles. Seventy bodies equal in size to the Earth would have been required to cover up this gap in the photosphere. Most spots, however, are by no means so gigantic as was this particular example.

Sunspots reveal to astronomers many important facts. They show that the Sun, like the Earth, rotates on its axis. By observations of the displacements of many spots, astronomers have found that the rotation of the Sun is performed in twenty-five days at the equator, and twenty-seven and a half days at forty-five degrees north and south of the equator. That is to say, the Sun does not rotate as a whole. Different parts have different periods. The "day" of the Sun therefore is over twenty-five times longer than that of our planet.

Another remarkable fact which sunspots reveal concerns their own distribution. At some seasons spots are much more numerous than at others, and it has been ascertained that they increase and decrease in about every eleven years. Thus 1889 and 1901 were years of few sunspots, while 1893 and 1905 were years of many spots. The history of the discovery of the "solar cycle," as this increase and decrease is called, is one of the most interesting in the annals of astronomy. In 1826 a German apothecary named Schwabe, who was interested in the study of astronomy, commenced to count the number of spots on the Sun from day to day. His only instrument was a small hand telescope. After about twenty years he found traces of the increase and decrease, and by 1851 had fully proved the existence of the "sunspot period." Here was a discovery which had escaped all the great

astronomers, and fell to be made by an amateur. Besides the spots, the telescope reveals the existence of bright ridges which are known as "faculæ." These are usually observed close to the spots. Like them, they are far from being permanent features. Even in a few hours they utterly change their shape, and in some cases it is impossible to sketch their form, so quickly do they alter and disappear. Although they are closely connected with spots, there is one remarkable difference. Spots are usually confined to two zones above and below the solar equator, while faculæ are found in every latitude, except in the polar regions.

It is important to remember that the greater part of our knowledge of the Sun has been derived from observations not with the telescope alone, but with the telescope aided by an instrument even more remarkable. This instrument is called the spectroscope, and in order to understand properly many of the latest and most wonderful discoveries in astronomy, it is necessary to have some idea of the principle of this instrument. Put briefly, it may be said that while the telescope reveals the celestial bodies, the spectroscope tells us the materials of which they are composed. Just as water can be broken up into its elements, oxygen and hydrogen, sunlight can be broken up into its primary colours, red, orange, yellow, green, blue, indigo, and violet. This can be done by passing sunlight through a prism of glass, and the strip of rainbow-coloured light which results is called the solar spectrum. In fact the rainbow is merely the solar spectrum produced naturally by what is known as refraction, the bending or deflection of the rays of the Sun. The solar spectrum was first investigated by Sir Isaac Newton, but it was not until the year 1814 that

Fraunhofer, a German astronomer, noticed in the spectrum a number of dark lines. He detected about three or four hundred of these, and named the more prominent by the letters of the alphabet from A in the red to H in the violet. He was greatly perplexed at first over the meaning of the lines. He found that they were conspicuous in the spectra shown by the Moon and planets, but not in the spectra of all the stars. In other words, the lines were found to be characteristic of sunlight, whether direct or reflected, and sunlight only. It is possible, however, to analyse other kinds of light besides sunlight. In a physical laboratory the lights of heated elements may be observed with the spectroscope, an elaborated form of the ordinary prism, and when each element is thus analysed it is found to be characterised by one or more bright lines. In 1859, Kirchhoff, a German scientist, showed that while a gaseous substance gives a spectrum of bright lines, a luminous solid, or liquid, gives a continuous spectrum. In the words of a lucid astronomical writer, "substances of every kind are opaque to the precise rays which they emit. That is to say, they stop the kinds of light or heat which they are then actually in a condition to radiate." This was the solution of the problem. All that astronomers had to do was to examine the spectra of heated elements and fix the position of the bright lines in these spectra, and afterwards compare the position of these lines with the position of the dark lines in the spectrum of the Sun. As the positions were in many cases identical, it became possible to ascertain of what substances the Sun was composed, and Kirchhoff was enabled to detect the presence in the orb of day of such well-known elements as sodium, iron, copper, zinc, and magnesium.

One of the uses of the spectroscope is to determine the elements of the Sun; but it has other uses. It has disclosed to astronomers the existence of another atmosphere. In the chapter on eclipses of the Sun, mention will be made of two solar features which are then seen to full advantage. These are the red flames or prominences, and the corona, a halo of silvery light. We do not see these features of the Sun every day, because they are obscured by its dazzling luminosity. When, however, the dark globe of the Moon interposes and cuts off the light of the photosphere, they are visible. By means of the spectroscope it is possible, however, to observe the prominences daily, and consequently our knowledge of these marvellous objects has greatly increased since the application to them of this instrument. They have been ascertained to be tongues of glowing hydrogen shot forth with tremendous power from the chromosphere, a thin layer surrounding the photosphere. Some of these prominences are enormous in height. An extraordinary outburst was witnessed on September 7, 1871, by the late Professor Young, one of the foremost solar observers. At noon he was examining a prominence by the spectroscope method. "It had remained unchanged since noon of the day previously—a long, low, quiet-looking cloud, not very dense, or brilliant, or in any way remarkable except for its size." At 12.30 A.M. the Professor left the spectroscope for a short time, and on returning half-an-hour later to his observations, he was astonished to find the gigantic Sun flame shattered to pieces. The solar atmosphere "was filled with flying *débris*," and some of these portions reached a height of 100,000 miles above the solar surface. Moving with a velocity which, even at the distance of 93,000,000 miles, was almost perceptible

to the eye, these fragments doubled their height in ten minutes. On January 30, 1885, another distinguished solar observer, the late Professor Tacchini of Rome, observed one of the greatest prominences ever seen by man. Its height was no less than 142,000 miles—eighteen times the diameter of the Earth. Another mighty flame was so vast that supposing the eight large planets of the solar system ranged one on the top of the other, the prominence would still tower above them.

Like the spots, the prominences increase and decrease every eleven years. The law which governs the number and distribution of the spots also governs the prominences. This eleven-year period governs more than prominences and spots. It also governs the shape of the corona, a silvery radiance which envelops the Sun outside of the chromosphere. The entire Sun is governed by this period, which as a result influences the other bodies of the solar system. Take the magnetic variations on the Earth. These magnetic variations indicate a period of almost eleven years. Not only the periods agree, but a great outburst of spots and prominences on the Sun is usually answered by a magnetic outbreak on the Earth. In February, 1892, a large group of sunspots appeared, and the result was great disturbances of the delicate magnetic needles kept at Greenwich and elsewhere. In February, 1907, another great group appeared. It was followed by a magnificent display of the Aurora Borealis, or Northern Lights, an electrical phenomenon which is caused by electrical discharges in the upper regions of the Earth's atmosphere. As Professor Gregory remarks: "Magnetic storms are generally accompanied by auroral displays, and *vice versa*. What is more, the frequency of auroras keeps time with the frequency of sunspots, and

therefore with the intensity and magnitude of magnetic variations." In a word, the Sun is the pulse of the solar system, from which all influences run outward.

We may now briefly review what is known of the constitution of the Sun. The central portion of the mighty orb below the photosphere has never been seen. In the words of an able writer, "Of the heat in the Sun's interior we can form no conception. The pressure within the Sun is equally inconceivable. A cannon ball weighing 100 lb. on Earth would weigh 2700 on the Sun. Thus a mighty conflict goes on unceasingly between imprisoned and expanding gases and vapours struggling to burst out, and massive pressures holding them down."

The first solar envelope is the photosphere, that bright calm-looking solar surface on which the spots appear and from which we derive our light. Above this are envelopes technically known as "the reversing layer" and the chromosphere. This latter envelope, from which the prominences emanate, may be described as a sea of fire, in a state of everlasting turmoil and unthinkable heat. Like the sea, it is restless and agitated, but its waves are waves of glowing hydrogen, and its spray fragments of shattered sun-flames. Beyond the chromosphere is the corona, a soft silvery radiance, which can only be seen when the Sun is totally eclipsed. The corona has long proved a problem to astronomers. Its shape varies in sympathy with the eleven-year period, and it seems closely connected with electricity and magnetism. It streams out from the Sun for millions of miles, becoming more and more rarefied until it gradually fades into the ether of space. It is the final solar envelope, calm and peaceful, a fitting crown for the orb of day.

This, then, is the Sun—ruler and centre of the Solar

System, to which we on Earth owe our light, heat, life. We cannot hope to realise fully the marvels of this mighty orb, or properly to appreciate the delicate mechanism, the marvellous contrivances which keep the grand central orb in touch with the little planets which circle round it. Without the Sun, not only would life on this planet be impossible, but our planet itself would not be in existence. In view of all this we can fully appreciate the remark of Proctor: "If there is any object which men can properly take as an emblem of the power and goodness of Almighty God, it is the Sun."

CHAPTER V

THE SUN'S FAMILY OF WORLDS

A STUDY of the globe of the Sun itself gives us an inadequate idea of the solar power. We cannot realise the extent of the Sun's influence until we comprehend the marvellous system of planets and satellites, asteroids, comets, and meteors which revolve round it. The Sun, as has been well said, "maintains in his rays the whole of his system. If the comparison were not offensive to the Sun-god, we might say that he is like a spider at the centre of his web. In the net of his attraction the worlds are sustained. Relatively to his magnitude and might, the planets are but toys spinning round him."

The planets are divided into three well-defined groups. Comparatively close to the orb of day, at mean distances ranging from 36 to 141 millions of miles, revolve the inner planets, consisting of four worlds—Mercury, Venus, the Earth, and Mars. Beyond the orbit of Mars we have another group, or rather ring, of seven hundred small worlds, the asteroids, planetoids, or minor planets. The largest of these is only five hundred miles in diameter. Beyond this, at mean distances ranging from 482 to 2789 millions of miles, we have the group known as the outer planets—Jupiter, Saturn, Uranus, and Neptune. Mere figures convey little or no idea of the relative distances of the planets. We may, however, represent the sizes and distances of the planets in imagination on a much smaller scale.

THE SUN'S FAMILY OF WORLDS

If we take a nine-foot globe to represent the Sun, we may represent Mercury by a large pea at a distance of 127 yards; Venus by a one-inch ball at 235 yards; the Earth by a one-inch ball at 325 yards; Mars by a half-inch marble at 495 yards, the asteroids by 700 small seeds at distances of from 676 to 1385 yards. Jupiter will be represented by an eleven-inch globe a mile away; Saturn by a nine-inch globe $1\frac{3}{4}$ miles away; Uranus by a four-inch globe $5\frac{1}{2}$ miles away. On this same scale we can represent the Moon as a pea moving in a circle at a distance of 30 inches from the ball, one inch in diameter, which represents the Earth. The actual diameters of the planets may be tabulated as follows:—

Inner planets.—Mercury	. . . .	3030 miles
,, ,, Venus	. . . .	7700 ,,
,, ,, The Earth	. . . .	7918 ,,
,, ,, Mars	. . . .	4230 ,,
The Asteroids.—From 500 to 10 miles		
Outer planets.—Jupiter	. . . .	92,164 miles
,, ,, Saturn	. . . .	74,000 ,,
,, ,, Uranus	. . . .	31,000 ,,
,, ,, Neptune	. . . .	34,000 ,,

From this table we see that the outer planets greatly exceed in size the inner planets, which in their turn dwarf to complete insignificance the asteroids or minor planets. The three groups, in fact, are completely different in distance, size, and physical condition.

Besides the planets, another class of bodies fall to be mentioned. The planets themselves, which revolve directly round the sun, are called primary planets. But most of the planets are themselves centres of little families of moons or satellites which revolve round them and are carried along with them round the Sun. These are called secondary planets, or, more usually, satellites. Mercury

and Venus have no satellites, and only two of the inner planets are attended by moons. We all know the Moon, the Earth's sole satellite world. Mars has two satellites, but they are very much smaller than the Moon. The asteroids, of course, have no satellites, because they are much smaller than satellites themselves. But the outer planets have imposing retinues of attendants. Jupiter boasts of no fewer than eight, four large and four small. Saturn is attended by ten worlds, and in addition has a ring of meteoric particles somewhat analogous to the zone of asteroids moving round the Sun. Uranus has four satellites, and Neptune, so far as we know at present, one. These satellites vary greatly in size, from Titan, one of the satellites of Saturn, which exceeds the planet Mercury in size, to the little satellites of Mars, which are certainly under thirty miles in diameter. The orbits or pathways of the various planets round the Sun lie almost in the same plane or level, with the exception of the orbits of some of the asteroids. Along these orbits the planets travel with different velocities.

Mercury	29	miles	per	second
Venus	21	,,	,,	,,
The Earth	18	,,	,,	,,
Mars	15	,,	,,	,,
Jupiter	8	,,	,,	,,
Saturn	6	,,	,,	,,
Uranus	4	,,	,,	,,
Neptune	3	,,	,,	,,

FIG. 2.—Comparative Velocities of the Planets.

Mercury, the nearest planet to the Sun, is subjected most to the Sun's attraction, and consequently travels fastest. Its velocity is twenty-nine miles per second, or 2,505,000 miles per day. Venus travels at over twenty-one miles per second, or 1,873,000 miles per day. The velocity of

our own planet is eighteen miles per second, or 1,555,000 miles per day. Mars travels at almost fifteen miles per second, which is equivalent to 1,287,000 miles a day.

The outer planets are more leisurely. Jupiter glides along at eight miles a second, or 771,000 miles a day. Saturn's velocity is over six miles per second, which is equivalent to 536,000 miles a day. Uranus travels at a little over four miles a second, and in one day covers 372,000 miles, while Neptune, the most distant known world, moves at the comparatively slow pace of three miles a second, or 268,000 miles a day. Comparatively slow in comparison with the other planets, but absolutely very fast, Neptune rushes along in its orbit with an almost inconceivable velocity. And if Neptune's speed is so great that it cannot be realised, it is almost impossible to conceive that our world, which seems to us so still and immovable, carries us along with it in its journey through space at the rate of eighteen miles per second and Mercury at twenty-nine miles per second. The following words of Flammarion bring out this clearly: "A ball fired from a cannon leaves the mouth with a velocity of 1312 feet per second, the terrestrial globe flies 75 times quicker, Mercury 117 times faster. This is a rapidity so stupendous that if two planets were to meet in their course the shock would be frightful; not only would they be shattered in pieces, both reduced to powder, but further, their motion being transformed into heat they would be suddenly raised to such a degree of temperature that they would disappear in vapour—everything, earth, stones, water, plants, inhabitants—and they would form an immense nebula." Fortunately we need have no apprehension of such a disaster. The planets are all moving in the same direction and they are at enormous distances from one

another. When Mars and the Earth are at their nearest approach, over thirty millions of miles separate them, while Venus, the nearest of all the large planets, is distant from us at its times of closest approach over twenty millions of miles.

As a result of these different speeds and different distances from the central orb of the various planets, the various bodies of the solar system require different times to perform their revolution round the Sun. Not only is Mercury closer to the Sun than is our own planet, and has therefore a smaller ellipse to traverse; it goes much more rapidly round its orbit, and therefore requires a much shorter period to perform a complete revolution.

The times of revolution of the various planets round the Sun may be tabulated thus:—

Mercury	88 days	
Venus	225 „	
The Earth	365 „	
Mars	687 „	
Jupiter	4332 „	(almost 12 years)
Saturn	10,759 „	(almost 30 years)
Uranus	30,687 „	(about 84 years)
Neptune	60,127 „	(about 165 years)

Just as the Earth's year is its period of revolution round the Sun, the year of Mercury is only 88 days, while that of Neptune is 60,127 of our terrestrial days, or almost 165 of our own terrestrial years. Thus, a being who had lived only twenty-four terrestrial years would be a centenarian on Mercury, while a man of eighty-four on our planet would be an infant of one year according to the length of years on the planet Uranus. In the Solar System, therefore, measurement of time is relative and depends on the distances of the various planets from the Sun.

As the different planets vary in distance, velocity, and size, they also differ in weight. Professor Gregory gives the weight of the Earth as 6000 millions of millions of tons. If we represent this by one pound, the weight of the Sun would be 150 tons; the weight of Jupiter would be 310 pounds; of Saturn 93 pounds; of Neptune 17 pounds; and of Uranus 14 pounds. The smaller planets, however, would be on the same scale, lighter than the Earth. Venus would weigh 13 ounces, Mars $1\frac{1}{2}$ ounces, Mercury 1 ounce, and the Moon about 3 drams. Although the outer planets are much heavier than the Earth, they are not so much heavier as they are larger, which shows that their density is less than that of the Earth.

On the Earth a falling body during the first second of its descent, falls through 16 feet. The following are the distances through which a similar body would fall on the other bodies of the solar system in the same time:—

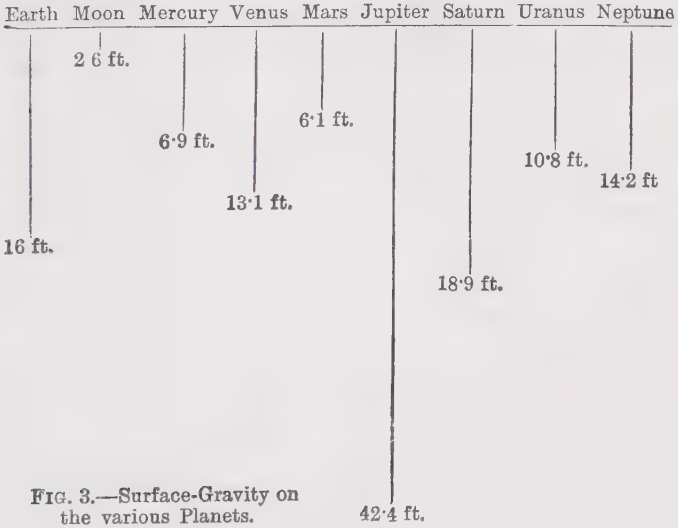


FIG. 3.—Surface-Gravity on the various Planets.

On the same scale the distance fallen on the Sun is too large to be shown—442·4 feet.

The weight of the body at the Earth's surface is the force with which the Earth attracts that body and depends on the mass of the Earth. Therefore, as the planets have different masses, a body if weighed on the different planets would have different weights. Take the case of a man who weighs twelve stones on the Earth. On the Sun he would weigh two tons. As Sir Robert Ball puts it, if a man were to be transferred to a globe as massive as the Sun, everything would weigh twenty-seven times as much as it does on the Earth. "To pull out your watch would be to hoist a weight of about five or six pounds out of your pocket. Indeed I do not see how you could draw out your watch, for even to raise your arm would be impossible—it would feel heavier by far than if it were made of solid lead. It is, perhaps, conceivable that you might stand upright for a moment, particularly if you had a wall to lean up against, but of this I feel certain that if you once got down to the ground, it would be utterly out of your power to rise again." Thus, a man living on such a globe would be unable to rise out of his bed in the morning.

A man weighing 12 stone on our world would weigh 28 stone on Jupiter, 14 stone on Saturn, 10 stone on Neptune, Uranus, and Venus. On Mars and Mercury the weight would be reduced to 5 stone, on the Moon to 2, while on the asteroids it would come down to a few ounces. Let us suppose a man of 12 stone placed on the Moon. He would be amazed to find everything one-sixth as heavy as on the Earth. His own weight would be so diminished that he could jump over a house with as little effort as he could on Earth leap across a wayside ditch.

Pulling out his watch he would feel practically no weight at all. A horseman who on Earth would consider a five-barred gate a good jump, would on the Moon leap over a hayrick with the same amount of exertion. Suppose a man were playing cricket on the Moon. On Earth 100 yards is a very good throw; on the Moon one of 600 yards would be accomplished with the same amount of exertion. One able astronomer puts this lessened gravity very clearly:—"Football would show a striking development in lunar play; a good kick would not only send the ball over the cross-bar, but it would go soaring over the houses and perhaps drop in the next parish."

If our imaginary man of twelve stones weight were transferred to one of the asteroids which circulate between Mars and Jupiter, his weight would be reduced to a few ounces. Suppose he kicked a ball into the air as an ordinary player would do on Earth, it would not, as in the Moon, go soaring over the houses; it would go soaring into space and leave the planet for ever. The force of gravity on the little asteroid would not be sufficient to counteract the upward motion of the ball, which would rush into space on a career of its own, and become a little asteroid on its own account. These illustrations bring home clearly the different masses of the various planets composing the solar system.

For reasons which will be explained later, the planets have different densities. Thus Mercury is in proportion to its size a very heavy planet. Its density is equal to that of zinc, which means that it weighs the same as a globe of zinc the same size. The weight of our Earth is equal to that of a globe of arsenic the same size. The densities of the other bodies of the solar system vary considerably. That of Venus is equal to iron pyrites,

that of Mars to ruby, and that of the Moon to flint-glass. The Sun and the four large planets, although so much superior to the inner planets in size, have smaller densities. The Sun and Jupiter weigh the same as globes of dry sand the same size, while the densities of Uranus, Neptune, and Saturn are equal to those of amber, boxwood, and walnut-wood.

The key to the different velocities, densities, and masses of the planets is the marvellous power of gravitation, which was referred to in the opening chapter, and the complete investigation of which we owe to the genius of Newton. Not only the planets and their satellites, but the various comets and the systems of meteoric rings conform to this mighty law which extends throughout the entire length and breadth of the Universe. Gravitation is the marvellous invisible bond everywhere present, operating throughout all space, which keeps the planets in subjection to the Sun, and which maintains order instead of chaos, harmony instead of discordance. Much as astronomers know of the operation of gravitation, of its nature they are entirely ignorant. In contemplating this marvellous force which so far has baffled science, the mind is lifted right into the region of things Divine and Eternal.

In this chapter we have briefly referred to the system of planets surrounding the Sun. The solar system is not only a system, but a system of systems, for, as we have seen, the various planets with their satellites form subordinate systems within the larger one. To explain the outstanding features of these planets and satellites will be the task of the next few chapters.

CHAPTER VI

MERCURY—"THE SPARKLING ONE"

SO far as we know, Mercury is the nearest planet to the Sun. The existence of a world at a less distance than Mercury was suspected, and indeed generally believed in, half a century ago. There were certain irregularities in the motion of Mercury which astronomers attributed to the action of an unseen planet. One observer boldly announced that he had seen the planet crossing in front of the Sun, and so the name of Vulcan was bestowed on the supposed world. But Vulcan was never seen again, and accordingly the great majority of astronomers believe that it never was seen—in fact, that no such planet exists.

Mercury, therefore, is the nearest known planet to the Sun. Seen from the Earth, the little orb is never far from the day star. Mercury revolves round the Sun in an orbit within that of the Earth, and consequently it is never to be seen on a dark sky in the opposite part of the heavens to the Sun. In Britain, Mercury is rarely visible, so close does it keep to the orb of day. In fact, it is recorded of Copernicus, to whom we owe the true theory of the planetary motions, that although he often looked for the planet, he was never successful in seeing it. The reason of his failure is not far to seek. He lived the greater part of his life near the valley of the Vistula, in Poland, where the horizon is rarely free from mists, and

MERCURY—"THE SPARKLING ONE"

Mercury is never very far above the horizon. Notwithstanding the difficulty of seeing it, Mercury has been known from the earliest times. The ancient Greeks were well acquainted with it, and it was sometimes known to them as the "sparkling one." This name was given to it because it does not, like the other planets which rise high in the heavens, shine with a steady light. As we always see it through the more or less misty air about the horizon, it twinkles and sparkles in a beautiful manner. Hence the name which the ancient Greeks so poetically conferred on the little planet.

As Mercury, owing to its proximity to the Sun, is difficult to observe with the unaided eye, it is also difficult to observe with the telescope. The opportunities of favourable observation are few, so closely does it follow the Sun. The first thing which impresses the telescopic observer of Mercury is that the planet exhibits phases similar to those of the Moon. As the Earth's path encloses the orbits of both Mercury and Venus, we never see these planets fully illuminated. To be fully illuminated a body must be in the opposite quarter of the heavens from the Sun, like the Moon at the full phase. Sometimes, however, Mercury is at the opposite side of the Sun from our planet. That is to say, we have Mercury, the Sun, and the Earth all in a straight line, with the Sun between the Earth and Mercury. The planet is then at its farthest from the Earth, but could we observe it we should see it with a fully illuminated disc; in fact, we should have "full Mercury." We do not see the planet at these "superior conjunctions" as such occurrences are called, for Mercury is then lost in the glare of the Sun and quite invisible to the terrestrial observer. After a time, however, the planet, in its journey round the orb

of day, reappears from the solar glare as an evening star. As it comes nearer and nearer to the Earth, and as its disc becomes apparently larger, the illuminated portion decreases, until we have only "half Mercury," then a crescent Mercury, until, when the planet is at its nearest, the thin crescent disappears altogether and we soon have "new Mercury." Like our satellite at new Moon, Mercury becomes invisible. Technically it is said to be at "inferior conjunction," because the Earth, Mercury, and the Sun are in a straight line, with Mercury in the centre, the result being that the bright side of the planet is turned towards the Sun and away from the Earth. Then on its journey round the Sun, Mercury again appears as "morning star." Only a little crescent is at first visible in the telescope, but gradually the illuminated portion becomes greater as the planet recedes from the Earth and the apparent diameter decreases. Again we have "half Mercury," and again the planet disappears in the rays of the Sun to reappear as an evening star.

Thus we are placed at a disadvantage in regard to the observation of Mercury, because the planet revolves round the central orb within the orbit of the Earth. When Mercury is nearest to us it is invisible. When it is fully illuminated it is also invisible. We only see it bit by bit, as it were, at its various phases. Above all, it is so near the Sun that astronomers are never able to observe it on a dark background, and it is so low in the heavens that it is always seen through a stratum of thick air.

For many years nothing was known of the surface of Mercury. At the beginning of the nineteenth century, however, a series of observations were made by Schröter,

an able German astronomer of that day. Schröter was anxious to ascertain the period of Mercury's rotation on its axis—the length of the planet's "day." Schröter detected certain markings, and from the motions of those he concluded that the rotation of Mercury was performed in about twenty-four hours, similar to our own terrestrial day. For many years this estimate was generally accepted, although owing to the great difficulty of observing the planet it was not implicitly relied on.

Some distinguished astronomers, however, were not content with a mere unconfirmed estimate of the length of Mercury's day. Among these was Schiaparelli of Milan, who, in 1882, commenced a prolonged series of observations of the planet for the purpose of determining the rotation period. Previous observers had been handicapped by the fact that Mercury when visible as an evening or morning star is to be seen for only a short period. Therefore prolonged observations of the planet are impossible under such conditions. Schiaparelli struck out a new line. Instead of observing Mercury at the usual time, he followed it by day, considering that the disadvantage of observing the planet in the day-time was more than compensated by the advantage of prolonged observation. He followed the planet for hours at a time, and at last, after seven years' observations, he announced his discoveries. They were as startling as they were unexpected. He found that so far from the planet rotating on its axis in twenty-four hours, the markings visible remained fixed in position, and that the planet performs only one rotation on its axis during its revolution round the Sun. Instead of rotating in twenty-four hours, as the Earth does, it rotates in eighty-eight of our terrestrial days. Controversy raged for some years among astro-

nomers as to the accuracy of this result, but now the truth of Schiaparelli's discovery is generally accepted.

Let us try to imagine what sort of a world Mercury must be. Rotating on its axis only once during its journey round the orb of day, it turns the same face to the Sun just as the Moon does to the Earth. One face

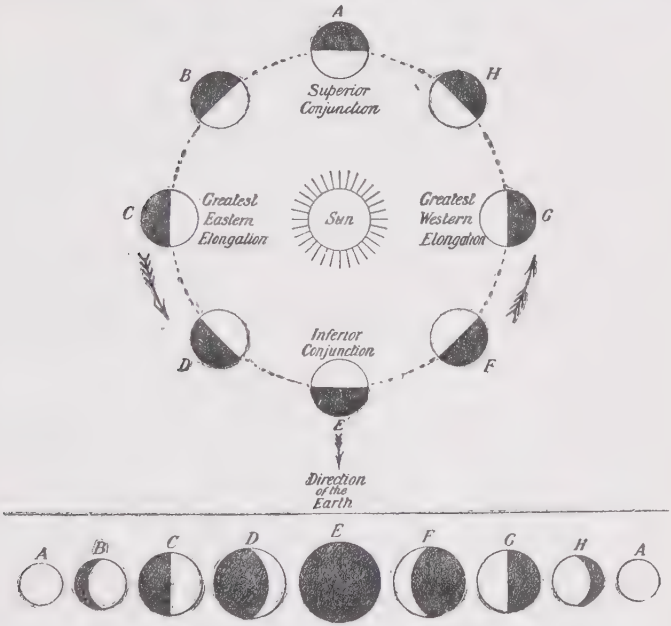


FIG. 4.—Orbit and Phases of an Inferior Planet.

of the planet is bathed in perpetual sunshine, the other is shrouded in everlasting night. One side is baked with heat, and the other is frozen with cold. No wonder that the surface, as the observations of Professor Lowell indicate, is cracked in all directions. The surface of Mercury, he says, is colourless: "a geography in black and white."

However, there is a small zone on the planet's surface on which the Sun does rise and set—owing to the irregular motion of the planet in its path, its varying velocity due to the eccentricity of its orbit, and its uniform motion on its axis. This is clearly explained by Mr. Gore in the following words: "This difference in the regularity of the two motions will of course give rise to a 'libration,' which will have the effect of bringing a portion of the dark side of Mercury periodically into the sunlight, and will thus diminish the area of the planet's surface which is shrouded in perpetual night. About three-eighths of the total surface will for ever remain in darkness, three-eighths in perpetual sunshine, while the remaining one-fourth will have alternately day and night. In fact, an inhabitant living near the mean bounding line and on the planet's equator would have forty-four days of sunshine and forty-four days of night and twilight. A little farther in on the dark side there would be perpetual twilight; and farther in still, eternal night would reign. Owing to the low altitude attained by the Sun near the bounding line, its intense heat and light would of course be much mitigated, so that probably this region of the planet's surface may be comparable with the temperate zones of the Earth."

Little is known of the markings of Mercury. The few observations which astronomers possess seem to indicate that the surface is rugged and mountainous, somewhat similar to that of the Moon. As to whether there is an appreciable atmospheric envelope surrounding Mercury, opinion is divided, some holding that the globe of Mercury is, like that of our satellite, airless, others believing that there is an atmosphere surrounding the little planet.

The general opinion of astronomers is that under such

conditions as exist on Mercury, life, as we know it, is impossible. If there are inhabitants of Mercury, they must, from the dark side of their world, obtain magnificent views of the outer universe. Venus and the Earth will shine with a glorious radiance, fully illuminated. The Earth and Moon seen from Mercury form a fine double star. The Earth will appear a magnificent object, attended by a little star of the third magnitude. The brightest object in the evening skies of Mercury will be Venus, as the little planet has no satellite circling round it and illuminating its dark hemisphere.

CHAPTER VII

THE EVENING STAR

FROM the earliest ages the planet Venus has been known to, and admired by, mankind. No record exists of the recognition of this beautiful planet as distinct from the ordinary stars, for of all the "wanderers" Venus, as the brightest, would probably be the first to be detected. Homer refers to the star as the "star of Lucifer," and one distinguished astronomer holds that under the title of "Mazzaroth" it is referred to in the Book of Job.

Venus is both the evening star and the morning star. That is to say, the phenomena known as evening star and morning star are different appearances of the same orb. The earliest astronomers amongst the Greeks did not know this. The morning star they called "Phosphorus" and the evening star "Hesperus," and for many years the two were believed to be separate bodies. It was noticed, however, that when the evening star was to be seen in the evening, there was no trace of the morning star on the following morning, and that conversely when the morning star was visible, it was hopeless to expect to see it at night at the same period. Pythagoras, the famous Greek thinker, is believed to have been first in identifying the two stars as one—the evening and morning star.

Venus, like Mercury, exhibits phases when observed with the telescope. As Venus is so much nearer than Mercury, and is a much larger planet, these phases are much more

easily observed. To the unaided eye Venus is but a luminous point, bright enough on rare occasions to cast shadows, but with no definite shape. When, however, we turn even a small telescope on the evening star, a remarkable change is wrought. The beautiful soft luminous point is transformed into an exquisite little disc of varying phases, for Venus, in Galileo's phrase, "imitates the phases of the Moon." The existence of these phases was affirmed by Copernicus when he propounded the theory of the planetary system. The existence of these phases was a necessary proof of his contention that the planets went round the Sun, and not round the Earth. It was pointed out to Copernicus that no phases of Venus could be seen, and in those days there were no telescopes. "God," replied Copernicus to his critics, "will cause instruments to be invented to improve the sight and then you will see them." Soon after the invention of the telescope, in 1611, Galileo turned his instrument on the evening star, and there, in the field of the telescope, shone an exquisitely beautiful miniature of the Moon, going through each of our satellite's phases. As a telescopic object Venus is indeed beautiful. The observation of the planet is a source of never-ending delight. No one can avoid feeling a thrill of pleasure as he beholds the beautiful evening star, shining out softly in the twilight, with its calm and rich radiance, transformed by the telescope into an ever changing golden disc, sharply defined in the evening light.

The phases of Venus are similar to those of Mercury. At "superior conjunction" the disc of the planet is fully illuminated, but it is lost in the rays of the Sun. Then the planet emerges from the sunlight as "evening star." When it reaches its "greatest elongation east," the disc is half illuminated like the Moon at the quarters. As

the planet approaches the Earth the disc increases in size, but the illuminated portion decreases until the planet, a dwindling crescent, is again lost in the rays of the Sun at "inferior conjunction," and we have "new Venus." The planet is at its nearest only some twenty-six millions of miles from the Earth, but it is invisible. Shortly after this it reappears as morning star, a thin crescent increasing in size, and its apparent diameter decreasing. When it reaches its "greatest elongation west," Venus is in its best position for observation as morning star. The disc becomes smaller, more and more of it becoming visible, until it draws close to the Sun, once again passes superior conjunction, and emerges from the sunset as evening star.

Our knowledge of the configuration of the surface of the planet is very limited, for two reasons. In the first place, Venus is, like Mercury, unfortunately placed for observation. It is, of course, easier to observe than Mercury, being much farther from the Sun and much larger, but, like that orb, it is never seen on a dark sky, and never observed for a protracted period. In the second place, the planet is so dazzlingly bright that it is very difficult to observe markings on its surface. Venus reflects a greater proportion of the light which it receives from the Sun than any other planet. As Mr. G. F. Chambers remarks in his book, "The Story of the Solar System," "the reflective power of Venus was probably never more effectively brought under the notice of a human eye than on September 6, 1878, when Nasmyth enjoyed an opportunity of seeing Venus and Mercury side by side for several hours in the same field of view. He speaks of Venus as resembling clear silver, and Mercury as nothing better than lead or zinc. Seeing that owing

to its greater proximity to the Sun, the light incident on Mercury must be three and a half times as strong as the light incident on Venus, it follows that the reflective power of Venus must be very great." This reflective power has been estimated as equal to that of newly fallen snow. The evening star reflects seventy per cent. of the light which falls on it. What is the reason of this remarkable reflective power? The generally accepted explanation is that the planet is surrounded by a very dense and cloud-laden atmosphere, and that the sunlight falls on these clouds. In other words, we rarely catch a glimpse of the surface of Venus. This is fully confirmed by observation of the planet. It is only with the greatest difficulty that the markings can be detected.

As in the case of Mercury, the length of the planet's day has been for many years a matter of controversy. Observations made in the seventeenth century by the famous astronomer, Cassini, indicated that Venus turned on its axis in a period of about twenty-three hours. At the same time, however, another astronomer, Bianchini, made observations which suggested a period of twenty-four days, eight hours. The German astronomer Schröter, tackled the question at the end of the eighteenth century, and confirmed the short period of twenty-three hours. In 1839 an Italian astronomer, Di Vico, confirmed these observations, and for fifty years the twenty-three hour period was generally accepted. It was the same distinguished astronomer who showed the probability of the long rotation period of Mercury who made the same discovery in regard to Venus.

A series of observations, extending over thirteen years, convinced Schiaparelli that the markings noted by the earlier observers were not really permanent. As in the

case of Mercury, he observed the planet by day, and was enabled to follow it for hours at a time. He concentrated his attention on round white spots which remained fixed in position. The obvious conclusion to be drawn from this is that Venus performs only one rotation on its axis in its period of revolution round the Sun—225 days. One face of the planet is constantly turned to the Sun, and in continuous sunlight; the other face is always turned from the Sun, and is in everlasting darkness. In the case of Venus there is not the same amount of "libration" as in that of Mercury. The pathway of Venus is much more nearly circular, and the variation of velocity is much less than in the case of the smaller planet, so that only a very small part of the surface will enjoy the alternation of night and day as does a considerable portion of Mercury.

Since Schiaparelli announced his results, a number of different observers have made observations to determine the rotation period. The period of 225 days has been abundantly confirmed by observers favoured by good climates and clear skies, while astronomers in less favourable climates supported the short period. It may be now taken as very probable therefore that Venus rotates on its axis in the same period as it requires to revolve round the Sun

Little is known of the physical condition of the planet owing to the dense atmosphere which surrounds it. Polar "caps," supposed by some to be somewhat similar to those on our own planet and on Mars, have been observed, or at least "suspected," from time to time. Some astronomers, however, do not regard them as snow; the drawings of Schiaparelli represent them as separated by a dark shadow, which suggests that they represent two mighty mountain systems. Evidence of the mountainous condition of Venus was obtained by Schröter as long ago as

the beginning of last century. He noted the southern "horn" of the planet when in the crescent form to be blunted, and he attributed this to the existence of a great mountain, five or six times higher than the loftiest peaks on the Earth. Along the terminator, or the dividing line between light and darkness, he noted irregularities which he considered to be more strongly marked than those on the Moon. These observations have since been only partly confirmed. Still there seems fairly strong evidence that the surface is rocky and mountainous, although not so mountainous as was believed by Schröter. Trouvelot, a French astronomer, found in 1878 the polar spots distinctly visible. "Their surface," he wrote, "is irregular, and seems like a confused mass of luminous points, separated by comparatively sombre intervening spaces. This surface is undoubtedly very broken, and resembles that of a mountainous district studded with numerous peaks, or our polar regions with numerous ice-needles brilliantly reflecting the sunshine." These features, then, are either striking enough to be seen through the dense cloud-canopy which surrounds Venus, or else they are high enough to project above the dense portions of the atmosphere.

Of the existence of the atmosphere there is no doubt. It has been actually observed when the planet is in "transit" across the face of the Sun. Spectroscopic observations show that water vapour exists in the atmosphere, which is very dense. Seen from the Earth, this atmosphere seems the very picture of calm and quiescence. But if the long period of rotation indicated by Schiaparelli's observations be correct, it can scarcely be a calm region. As a recent writer puts it: "The atmosphere circulation of Venus must be conducted by a permanent hurricane system. A violent uprush of heated air on the side perpetually

exposed to a glare twice as fierce as that of our hottest sun, should be compensated for by a furious inrush on both sides of the illuminated hemisphere, like the draught caused by a fire in a cold room."

Venus has no satellite, in this respect resembling Mercury. For many years, nevertheless, a search for a satellite was prosecuted with great energy, and it was believed by several astronomers that they had detected a companion-world. It was afterwards shown, however, that what they had taken for satellites must have been either optical illusions, caused by the glare of the planet in the field of the telescope, or small stars which happened to lie in the same field of view as the planet. Thus, although in size resembling the Earth more than any other world, it differs from our planet in several important respects; its "days" are utterly different from ours, and it has no Moon to circle round it and perform the useful offices of satellite-world.

The question of the habitability of Venus has attracted little attention. Certainly the planet, with its remarkable rotation period, and its dense atmosphere, does not seem an inviting abode. On this point, however, astronomers know too little to speak with confidence. Sir Robert Ball inclines to the view that even though Venus does rotate in the way that the majority of astronomers believe, "we might expect to find in that planet a luxuriant tropical life of a kind perhaps analogous to life on the Earth." If there are inhabitants of Venus, and if ever they catch a glimpse of the outer universe, their eyes will be gladdened by a beautiful celestial spectacle such as we on this planet are not privileged to see. The Earth and Moon, combined, probably appear more brilliant to Venus than Venus does to us, and the two orbs—the smaller moving round the larger—form a beautiful and imposing double star.

CHAPTER VIII

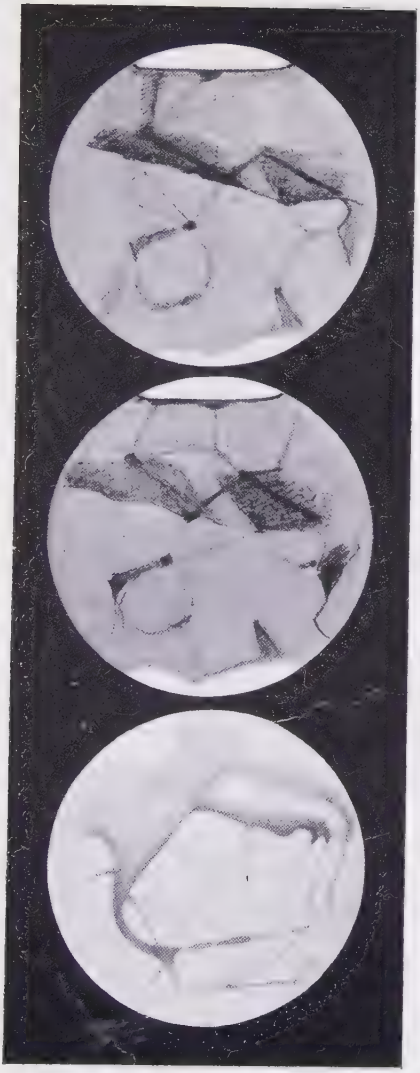
MARS—THE RED PLANET

AS was shown in the previous chapters, Venus revolves round the Sun in an orbit wholly within that of the Earth, and consequently is not seen by us to full advantage. When nearest, the planet is invisible; it is in a straight line between the Earth and the Sun, and turns its dark hemisphere to our planet. With Mars the case is entirely different. Mars revolves in an orbit exterior to ours, and when nearest to the Earth is on the other side of our planet from the Sun. The Sun, the Earth, and Mars are in a straight line with the Earth in the middle. If the near approaches of Venus correspond to "New Moon," those of Mars correspond to "Full Moon." We then see Mars with a full round disc. The planet is said to be "in opposition" to the Sun, because it is in the opposite quarter of the heavens. It rises at sunset, culminates at midnight, and sets at sunrise.

Mars as a celestial spectacle is usually inferior to Venus. But at times its brilliancy becomes extraordinary, and the planet shines with a bright ruddy light which makes it one of the most striking objects in the heavens. In the words of a famous modern astronomer: "Once in every fifteen years a startling visitant makes his appearance upon our midnight skies—a great red star that rises at sunset through the haze above the eastern horizon, and then, mounting higher with the deepening night, blazes forth

against the dark background of space with a splendour that outshines Sirius and rivals the giant Jupiter himself. Startling for its size, the stranger looks the more fateful for being a fiery red. Small wonder that by many folk it is taken for a portent." It is recorded that in 1719 Mars was so brilliant that a panic ensued among the ignorant. Owing to the comparative nearness of Mars to our world—at times about thirty-five millions of miles—along with its favourable presentation when closest to the Earth, we know more of the surface of Mars than of any other body in the entire Universe, with the single exception of the Moon. For over 250 years Mars has been attentively studied by astronomers. It was observed by Galileo, who, however, discovered nothing important. In 1656 the Dutch astronomer, Huyghens, made the first determination of the length of the Martian day, the period of the planet's rotation on its axis. Unlike Mercury, Mars has a day somewhat similar to our own, the length of which has been known for over two centuries. The exact length, to within a fraction of a second, is 24 hours 37 minutes 22·65 seconds, only about half-an-hour longer than the day of our own world. Its year, therefore, which consists of 687 of our days, contains 669 of its own. In another particular Mars closely resembles the Earth. The inclination of its axis to the plane of its orbit is about 66 degrees; its seasons, therefore, closely resemble those on the Earth. Another remarkable point of resemblance was noted almost two centuries ago. In 1719 the French astronomer Maraldi discovered two white spots on the disc of Mars—one at the north pole, the other at the south. These spots correspond to the polar regions of our own planet.

Like the Earth, Mars has an atmosphere, but it is



THE PLANET MARS

The two uppermost drawings are by Professor Lowell, July 8 and 12, 1907. The lower drawing is by Professor Schiaparelli, May, 1890. On each the polar caps and the famous canals are visible.

much thinner than our own, "thinner at least by half," says Professor Lowell, "than the air on the summit of the Himalayas." Clouds and obscurations seem to be very rare in the Martian atmosphere. It is very clear and transparent, and it is believed not to differ much from our own in constitution. The following description of this Martian atmosphere is from the pen of the late Miss Agnes Clerke: "This slender envelope is exceedingly extensive. In the pure sky, scarcely veiled by it, the Sun diminished to less than half its size at our horizons, probably exhibits its coronal streamers as a regular part of his noontide glory; atmospheric circulation proceeds so tranquilly as not to trouble the repose of a land 'in which it seemeth always afternoon.'"

Huyghens and other early astronomers detected various prominent markings, chief among them the well-known features known variously as the Kaiser Sea, the Hour-Glass Sea, and, in the now prevalent system of nomenclature, the Syrtis Major. It was not, however, until Herschel took up the study of Mars that much was known of its surface. He found that the spots at the poles waxed and waned in accordance with the Martian seasons—that is to say, the north polar cap increased in size during the winter of the northern hemisphere, and decreased in summer, while the reverse process took place in the southern hemisphere. He concluded, therefore, that the polar spots were masses of snow and ice, similar to the polar regions of the Earth. After the planet had been attentively studied by Beer and Mädler, Dawes, Secchi, and other astronomers, the late Mr. Proctor constructed a map of Mars in 1869 from drawings by Dawes. He gave names to the various features, the red portions of the planet's disc being known as continents, and the green as seas, in

accordance with the prevailing views of contemporary astronomers. Along with this he put forward in "Other Worlds than Ours," some very fascinating and plausible ideas of the habitability of Mars, which he named a "miniature of the Earth," having continents, oceans, snow, rain, clouds, rivers, and probably inhabitants. The researches of the last twenty-eight years, however, have revolutionised our knowledge of Mars. The close analogy which Proctor perceived has vanished, and Mars is now considered as an emblem of what our world will be in the future rather than as a miniature at present. The most recent observations have changed but not destroyed the analogy.

It was in 1877 that the revolution in our views concerning Mars began. In the words of Mr. Percival Lowell: "Our knowledge of the planets, and especially of Mars, has advanced greatly within the last quarter of a century. The first steps of this advance we owe not to instruments, but to the genius of one man—the Italian astronomer Schiaparelli."[1] When in September 1877 the planet reached its opposition, this famous astronomer commenced a trigonometrical survey of the planet's disc. While so employed he discovered a number of fine dark lines crossing the red areas of the planet. He called them "canali," an Italian word meaning canals or channels. In 1879 Professor Schiaparelli again observed the canals, which revealed the same appearance as they had done two years previously. Towards the end of the year he was amazed to find that one of the canals had become double—a new canal running parallel with the original one. Suspecting optical illusions he

[1] It is claimed that some of the more prominent canals had been noted by Mr. Maunder and other English observers before 1877.

changed his telescopes and eye-pieces, but was soon convinced of the reality of his observations. In 1881 he again saw the canals, double and single; and during the unfavourable oppositions of 1884, 1886, and 1888, he went from discovery to discovery. Indeed, he declared in 1888 that the canals had all the distinctness of an engraving on steel with the magical beauty of a coloured painting. Considerable scepticism prevailed in scientific circles for a number of years, as other astronomers could not see the canals, either double or single. At length, in 1886, nine years after the Italian astronomer made his discovery, the news flashed over the scientific world that his discovery was confirmed. In that year the astronomers at the Nice Observatory detected the canals. They were soon followed by a number of the most distinguished observers, both of Europe and America, who testified that the canals were there, however much astronomers might differ in their interpretation of them.

In 1892 Professor Pickering, observing in the fine climate of Arequipa, on the slope of the Andes in Peru, discovered at the junctions of the canals dark spots which he termed "lakes," in keeping with the view that the darker regions of the planet's surface are really aqueous; but his observations at the same opposition threw considerable doubt on this view. For the purpose of observing the planet thoroughly during the favourable opposition of 1894, Mr. Percival Lowell erected a special observatory at Flagstaff, Arizona. Observations were there commenced on May 29, 1894, by Mr. Lowell and his assistant, Mr. Douglass, and were continued until April 3, 1895, when the favourable season for observation came to an end. Altogether, Mr. Lowell mapped out three hundred and fifty canals, and obtained confirmatory

evidence of the existence of lakes discovered by Professor Pickering. Instead of lakes, Mr. Lowell prefers to call them "oases."

At the same time Professor Lowell made what he calls a Martian polar expedition. On 3rd June 1894 he measured the south polar cap when it stretched "almost one unbroken waste of white," over about 55 degrees of latitude, its diameter across measuring 2035 miles. As it melted there was observed surrounding it a broad blue belt, and as the cap contracted the belt, which evidently represented the water let loose by the melting of the cap, also decreased in size. In August 1894 it was, in Professor Lowell's words, "a barely discernible thread drawn round the tiny white patch, which was all that remained of the enormous snow fields of some months before." On 12th October Mr. Lowell noted in his diary: "Polar cap has been very faint for some time; barely visible." On the following day his assistant, on turning the telescope on Mars, was amazed to find that the cap had vanished. This was the first occasion on which the snow cap was seen to disappear; and this shrinkage or disappearance of the cap apparently holds the key to the various problems of the Martian disc.

By this time several theories had been put forward to account for the phenomena of the planet's surface. Proctor had thrown out the hint that the canals were rivers, but this idea was soon thrown aside. Various other astronomers regarded the canals as cracks in the planet's surface, as swarms of meteors ploughing tracks above the planet, and as chains of mountains running over land and sea; but each of these hypotheses was in turn abandoned as untenable. In the end of 1895 Mr. Lowell's views on the planet—the result of his own observations—were given to

the world in his book, "Mars." Mr. Lowell concludes that the reddish ochre portions of the planet—the "continents" of Proctor—are desert land; that the dark regions are not seas, but marshy tracts of vegetation, and that the polar caps are composed of snow and ice. He adopts Professor Schiaparelli's view that the canals are waterways, lined on either side by banks of vegetation, as well as Professor W. H. Pickering's idea that the lines which we see are not the canals themselves—which are much too small to be seen—but the strip of fertilised ground surrounding them. The canals are distinctly connected with the melting of the polar cap, and grow darker as the cap melts, just as if water was being conveyed along them. All this is very easily explained by one assumption—namely, that the canals have been constructed by a race of intelligent beings for the specific purpose of bringing water from the melting polar cap to the equator. Mars is scarce of water; and if there are inhabitants they must be compelled to utilise every drop which they can secure. The oases are supposed by Mr. Lowell to represent centres of population where the inhabitants, driven from the desert land by scarcity of water, cluster about the ground artificially fertilised. Mr. Lowell also concludes that as Mars is an older planet than the Earth, the inhabitants are probably in a higher state of civilisation. Thus, all the complicated Martian phenomena are explained on the assumption that Mars is inhabited by a race of intelligent beings.

This theory was not cordially received, and astronomers began to consider if some other explanation would not be more probable. Most scientists inclined to what is known as the "optical illusion theory," put forward originally by the eminent Italian astronomer, Signor

Vincenzo Cerulli of Teramo, and independently by Mr. E. W. Maunder, of Greenwich Observatory, the well-known English astronomer. It was supported by Professor Simon Newcomb, who thus explains the "canaliform" appearance: "This phenomenon is not to be regarded as a pure illusion on the one hand, or an exact representation of objects on the other. It grows out of the spontaneous action of the eye in shaping slight and irregular combinations of light and shade too minute to be separately made out, into regular forms." A series of experiments made by Mr. Maunder in 1902 and 1903 were described by him in *Knowledge* for November 1903. In conjunction with Mr. Evans, headmaster of the Royal Hospital School of Greenwich, Mr. Maunder arranged for classes of two hundred boys to copy at different distances three views of Mars on which the canal system was not represented. As almost all the boys drew canals on the copies, Mr. Maunder considers that the optical illusion theory is finally proved. But Mr. Lowell answers him by the following criticism of the theory:—"It asserts that because of the tendency of the human eye to connect well-seen points by imaginary lines, therefore those on Mars are of this class; which is like saying that because a man may see stars without looking at the heavens, therefore those in the sky do not exist. The parallel is not simply for illustration; it is exact, for the nervous action of the optic lobes will similarly cause any one to see faint points of light in a darkened field of vision, and the whole art of the observer consists in distinguishing which of these phenomena are objective and which not. So with these lines. A little more experience than the boys possessed would have permitted of parting the true lines from the false."

Mr. Lowell's observations on Mars, at the opposition

of 1903, were distinctly confirmatory of this theory. He made use of his various drawings "to determine the degree of visibility of a given canal at different seasons of the Martian year." After eliminating all sources of error, Mr. Lowell was able to construct graphs or curves of the visibility of the canals, and thus formed a series of curves which he named cartouches. From a discussion of these cartouches, Mr. Lowell finds that the development of the canals does not commence until the polar cap begins to melt; but after the cap melts the canals develop down the latitudes past the equator into the opposite hemisphere. He finds that it takes the water fifty days to travel from latitude 72° N. to the equator, a distance of 2650 miles. "This means a speed of fifty-one miles a day, or 2·1 miles an hour, and here we confront the surprising part of the performance, for the transference takes place in the face of gravity. A particle of water or other liquid would know no inclination to move from where it found itself. Gravity would not solicit it to stir. Of its own accord it would not move from the pole to the equator. Now, as it does flow towards the equator, and with a remarkably steady progression too, the inference seems inevitable that it has been carried thither by artificial means." In 1905 and 1907 Mr. Lowell succeeded in photographing the canals. His first photographs secured a number of converts, if not to his opinion, at least to belief in these remarkable objects.

Mr. Lowell hailed his success in 1905 as the refutation of the opposing theory. As the photographic plate cannot be the victim of illusion the canals should, on the illusion theory, be represented by irregular dots instead of straight dark lines. As Mr. Lowell remarked

in a communication to the present writer, "the camera does not agree with the arm-chair critics of the canals, but will have it that these markings are lines." Nevertheless the supporters of the illusion theory still hold to a modified form of it. In their latest work, published in the end of 1908, Mr. and Mrs. Maunder have the following remarks: "Are these markings on Mars actually as we see them, or do we only see them like that? We have no right to conclude that the straight sharp even 'canals' we see on the surface of Mars are really as artificial as they seem to us."

Some remarkable observations of the canals were made by Professor Lowell at the "opposition" of the planet in 1909. On September 30 of that year, when the region known as the Syrtis Major was presented to view, two very prominent canals became evident. "Not only," says Professor Lowell, "was their appearance unprecedented, but the canals themselves were the most conspicuous ones on this part of the disc. Many drawings were made, and in the course of the next few days the new canals were photographed, appearing on the plates as the most salient canals in their part of the planet. The record books were then examined, when it appeared that not a trace of them was to be found in the drawings of August, July, June, or May, when this part of the planet was depicted. That they had not been observed in previous years was then conclusively ascertained by examination of the records of those years."

Professor Lowell shows that these canals were never seen before, either by himself or by Schiaparelli, or by any other observer. "It might seem," he says, "that the absence on the charts was proof that a canal was itself new in the second sense, because it was so in

the first. But study of Mars has shown that this cannot be taken off-hand for granted; several points must each be carefully considered. In the first place, one must be sure that the phenomenon could have been seen before, yet was not. It must be of a size which could not have escaped detection previously. In the present case, however, this possibility of error was excluded by the size of the canals in question."

Mr. Lowell in his announcement of the discovery merely says that the proofs are clear that two new canals have developed. The inference in harmony with the theory which he maintains, that the canals are artificial, is that two new waterways have been constructed by intelligent beings. A good deal of scepticism has been aroused by a theory so startling, and few astronomers seem inclined to follow the American astronomer in the latest development of his theory. Still, if the theory in its general outline be correct, there is nothing either impossible or fantastic in Professor Lowell's explanation of the remarkable change which he has observed on the surface of Mars. Considerable space has been given here to the various theories of the canals, because these remarkable objects have not only attracted widespread attention, but have for years constituted a difficult astronomical problem.

As was pointed out at the beginning of this chapter, more is known of the surface of Mars than of any other body except the Moon. Our knowledge of the planet's geography, or rather "aerography," is well-nigh complete. As Professor Lowell says: "Aerography is a true geography, as real as our own. Quite unlike the markings on Jupiter and Saturn, where all we see is cloud, in the markings on Mars we gaze upon the actual surface

features of the Martian globe. They change in appearance, indeed, according to times and seasons, but they alter as true surface features would, not like cloud belts that gather to-day and vanish to-morrow." For these markings a number of different systems of names have been in vogue. Proctor was the first to draw up a real geography of the planet. He named the features after well-known astronomers, such as Herschel Continent, Mädler Continent, Dawes Ocean, Kaiser Sea. Flammarion drew up another chart, with a different set of names. For instance, the Kaiser Sea became in Flammarion's system, "Mer du Sablier." Green, another English astronomer, invented another system. Finally Schiaparelli re-named all the features on the disc, and in this nomenclature he is followed by Lowell and most modern students of Mars. His names are drawn from classical mythology, and, being Latin, have the advantage of commending themselves to astronomers of all nations. In this system the Kaiser Sea—the best known object on the red planet—becomes the Syrtis Major. The canals are named after mythological and real terrestrial rivers. Thus we find on Mars the Euphrates and the Ganges. This system devised by Schiaparelli is now in general use.

The canals vary greatly in length and in width. Many of them are about 2000 miles long. One known as the Eumenides-Orcus is 3540 miles, altogether an enormous length on a globe as small as Mars. The larger canals are estimated as from fifteen to twenty miles in width, and the smaller from two to three miles. As to their number, several hundreds have been catalogued by Schiaparelli and Lowell, and as the last-named astronomer says, "their name collectively is legion; while to name them individually is fast getting, for the number

detected, to be impossible." The geography of Mars is truly a marvellous one, so much does it resemble, and at the same time so much does it differ from our own. Whatever be our opinion of Professor Lowell's theory of their development, there is no doubt that Mars is relatively a much older world than the Earth, and that we see in it a world nearer to the end of life than our own, although relatively much younger than the Moon. For, as has been well remarked, "in space there are both cradles and tombs.

Mars has two satellites, which were discovered in the memorable year 1877. For forty or fifty years astronomers searched for satellites to the red planet. It was felt that as the Earth had one satellite, and Jupiter four, Mars should have at least one, if not two. But up to 1877 the search had been in vain. In that year, however, the late Professor Asaph Hall, aided with the large telescope of the Washington Observatory, detected two minute little satellites which circle round the red planet. In several respects these little satellites differ considerably from our satellite the Moon. In the first place, the Moon is comparatively a large body. These satellites of Mars, on the other hand, are very small. The diameter of Phobos, the nearer of the two to Mars, is estimated at 36 miles, that of Deimos, the more distant, at 10 miles. In the second place our satellite is at a considerable distance from the Earth—about 238,000 miles. The moons of Mars are comparatively close to their primary. Deimos revolves at a distance of 14,600 miles; Phobos at a distance of 5800 miles. Thirdly, our Moon is a leisurely body. It requires about 27 days to complete its circuit of the Earth. The Martian satellites are remarkable for the extraordinary rapidity of their motions. Deimos, the more distant of the two, revolves round Mars in 30 hours 18 minutes, while

Phobos completes a revolution in 7 hours 39 minutes. Now Mars requires over 24 hours to rotate on its axis. Phobos therefore revolves round Mars more than three times in one Martian day, an extraordinary state of affairs. As it revolves more swiftly than the planet rotates, it will not, like our Moon, seem to rise in the east and be carried westward, the result of the Earth's rotation in the opposite direction. This Martian satellite rises in the west, and crosses the heavens three times in one day. It overtakes Deimos and eclipses it, and runs through all its phases in eleven hours. Each phase lasts only three hours. Imagine a world with a Moon which could be seen in early evening at first quarter, and three hours later at the full. The satellites are so small, however, that they can be of little use to Mars in illuminating the evening skies.

If there are inhabitants of Mars, their skies will appear the same as our own. The stars and constellations are identical, but of course the different bodies of the solar system are differently seen. An able astronomical writer explains the appearance of the planets from Mars in the following words: "Jupiter is magnificent from Mars; it appears to the Martians half as large again as it seems to us, and his satellites should be easily visible to the naked eye. Saturn is likewise very brilliant, Uranus is easily visible, and they might have discovered Neptune before we did. They must have distinguished with the naked eye a large number of the small planets which revolve between their orbit and that of Jupiter. Mercury, drawn closer to the Sun, and lost in his rays, is almost impossible to distinguish. Venus appears to them as Mercury does to us. As for the Earth, how do they see it? . . . We are for that planet (Mars) a brilliant star presenting an aspect similar to that which Venus presents to us preceding

the dawn, and following the twilight; in a word, we are to the inhabitants of Mars the shepherd's star. Our natural vanity, then, might delude us with the idea that the inhabitants of Mars contemplate us in their evening skies purpled with the last solar rays; that they admire us from afar; that they have discovered our phases and those of the Moon as we have discovered those of Venus and Mercury; and that they suppose our world to be an abode of peace and happiness. Perhaps, even, they raise altars to us. What a disillusion if they could observe us a little nearer."

CHAPTER IX

THE ASTEROIDS

THE orbit of Mars marks the limit of the inner group of planets. These are separated from the outer group by what is variously known as the zone of asteroids, planetoids, or minor planets. They are, indeed, the most minute of bodies. Unlike their mighty neighbour Jupiter, and their comparatively large neighbour Mars, they are not to be seen without the aid of a telescope. The discovery of this zone belongs therefore to comparatively recent times, although the existence of one or more planets between the orbits of Mars and Jupiter was suspected fully three hundred years ago. In fact, Kepler, who gave to the world the "three laws" of planetary motion, predicted that a planet would be found revolving between the two bodies.

Belief in the existence of such a planet was strengthened, when, in 1772, a German astronomer named Bode investigated a curious relationship, since known as Bode's Law, connecting the distances of the planets. If we write down the following numbers, of which each after the second is double that preceding it—0, 3, 6, 12, 24, 48, and 96—and add four to each, we have another series—4, 7, 10, 16, 28, 52, and 100. Now it is a remarkable fact that these numbers represent approximately the proportions of the distances of the various planets from the Sun. Bode pointed out that 4 corresponded to the distance of Mercury, 7 to that of Venus, 10 to that of the Earth, 16 to that of

Mars, 52 to that of Jupiter, and 100 to that of Saturn. In 1781, another planet, Uranus, was discovered, and it was found that it filled the number 196. But there was not a planet at a distance corresponding to 28 between the orbits of Mars and Jupiter. Bode noted this fact, and stated his belief in the existence of a planet to fill the vacant space. In 1800, Von Zach, another German investigator, summoned a congress of astronomers to make a search for this remarkable body, whose existence was believed in before it was glimpsed by human eye. The Zodiacal region of the heavens was divided for the purposes of the search into twenty-four zones, each of which was assigned to a particular astronomer. Some astronomers were unaware of the fact that a zone of the heavens had been laid aside for their own particular attention. Among those who did not at the end of 1800 know of his own position among the band of searchers was Piazzi, the director of the Observatory at Palermo, in Sicily. On the first night of the nineteenth century—January 1, 1801—Piazzi was making observations for the purpose of forming a star catalogue when he noted particularly an eighth magnitude star. On the following night he ascertained that this was not one of the stars proper, but a body possessed of an appreciable independent motion. At first Piazzi believed that he had discovered merely a faint comet, but he soon came to the conclusion that he had found the missing planet. Accordingly he wrote to Bode at Berlin informing him of his discovery. Piazzi continued to observe the strange object for six weeks when he became unwell. By the time he was able to observe again the planet was invisible in the rays of the sun, and astronomers were afraid that it had been found only to be lost. However, an orbit was calculated from the few observations made by Piazzi,

and on the last day of 1801 the planet was again observed. It received the name of Ceres at the suggestion of the discoverer.

The gap had now been filled. The planet, it was true, was not comparable in size with any of the known planets of the solar system. It was so faint as to be invisible to the unaided eye. Still, astronomers believed that the missing planet had been found, filling the vacant space 28 of Bode's numerical progression. The solar system was now regarded as complete. Only three months after Ceres was rediscovered this opinion was rudely overturned. Olbers, a famous German astronomer, followed closely the new planet Ceres in the months following its rediscovery, and on March 28, 1802, he was astonished to find quite close to the position of Ceres another strange star of the eighth magnitude. A few hours showed him that this object was in motion. Here was a remarkable discovery. Not one, but two planets, revolved in the vacant space; and the new body—which received the name of Pallas—was found to revolve round the Sun at nearly the same distance as Ceres. The two bodies were without doubt akin to each other. The symmetry of the solar system was supposed to be broken, and no one was more astounded at the existence of two planets where one alone was expected, than Olbers, the discoverer of Pallas. At length he put forward his explanation of the presence of two small bodies. He supposed that there had existed between the orbits of Mars and Jupiter a large planet, of a kind similar to the other worlds of the solar system, and that, through some terrific catastrophe, this planet had in the remote past been shattered to fragments. He predicted that many more such fragments as Ceres and Pallas were likely to be found, and recommended that a search be made for other portions. In

1804, Harding, another German astronomer, discovered a third fragment, which was named Juno; and in 1807 Olbers, who had been maintaining a close watch, detected a fourth. The new planet was named Vesta, and is the brightest, though not the largest, of the asteroids. These four bodies were named the asteroids or planetoids, and for about forty years the system was again regarded as complete. It may be stated here that the theory of Olbers, although it led to the discovery of other two "fragments," is not now accepted by astronomers.

As no further asteroids seemed to be forthcoming, the search was abandoned in 1816. Fourteen years later, however, it was resumed. A German amateur astronomer, Hencke, ex-postmaster of Driessen, in Prussia, began to search for further members of the asteroid system. For fifteen years he watched without success. But at last, in December 1845, he discovered a fifth asteroid, which received the name of Astræa. A year and a half later he detected yet another, known as Hebe. In the same year an English astronomer, Hind, detected Iris and Flora, other two members of the system. Since 1847 not a single year has passed without the discovery of one or more asteroids. Some astronomers devoted almost all their time to the search for and discovery of minor planets. Peters, an American astronomer, discovered forty-eight. Palisa, an astronomer of Vienna, found over eighty, while Goldschmidt, Luther, Chacornac, and other observers each discovered many of these small planets. The method of discovery adopted by these astronomers was to construct charts of the regions round about the ecliptic in which such planets were likely to be found, and to compare those charts with the actual appearance of these regions of the

heavens through the telescope. By this method it was easy to pick out unfamiliar stars and identify them as new asteroids. This method, however, has now been discarded. A new method was devised in 1891 by Professor Max Wolf of Heidelberg, who has discovered over a hundred asteroids. It occurred to Dr. Wolf to apply photography to the detection of these objects. It is obvious that an asteroid, owing to its appreciable motion, will be represented on a photographic plate not as a point of light like the stars in the background, but as a streak of appreciable length. As Professor Brashear explains: "When the picture is developed, the stellar images show themselves as small circular dots, but if a planet were in the photographic field during the exposure, its image would be that of a very short line or trail about one-twentieth of an inch long, because it has an average movement through space of a little less than half the diameter of the Moon in twenty-four hours, while the stars remain practically stationary. This tiny trail is the clue to a new planet, or perhaps one already discovered." Since 1891 this method has been used extensively. In less than two years Dr. Wolf discovered seventeen asteroids. During the past eighteen years many minor planets have been detected in this way by Wolf and his assistants, and by Charlois, Metcalf, and other observers. The number of known asteroids now stands at about seven hundred.

By the time Dr. Wolf applied his photographic method popular interest in the ever-increasing family of little planets was on the wane. Mr. G. F. Chambers in 1895 described the asteroids as "of very little interest to anybody." It was hinted that there was no use continuing a search for bodies which so closely resembled

each other, and the discovery of which served no useful purpose to the discoverer. Certainly, it must have been a singularly uninteresting search for the astronomers who prosecuted it, because with so many asteroids already discovered there was always the possibility that the newly found object might not be a new asteroid at all, but merely a known one which had been lost to astronomers. Great care had to be taken to insure that the same planet was not "discovered" twice and regarded as two different objects. As Professor Turner, of Oxford, remarks: "There was a system of numbering in existence as well as of naming, but it was inadvisable to attach even a number to a planet until it was quite certain that the discovery was new, for otherwise there might be gaps created in what should be a continuous series by spurious discoveries being struck out. Accordingly it was decided to attach at first to the object merely a letter of the alphabet, with the year of discovery as a provisional name. The alphabet, however, was run through so quickly, and confusion was so likely to ensue if it was merely repeated, that on recommencing it the letter A was prefixed, and the symbols adopted were therefore AA, AB, AC, &c. After completing the alphabet again the letter B was prefixed, and so on." This was getting tiresome to the astronomical world, until at length in 1898 an insignificant little object was discovered on a photographic plate by Witt in Berlin, and designated as D.Q. It was seen that this was a real discovery, and to the little body was assigned the number 433, and the name of Eros. It soon appeared that this asteroid was of more interest and use to the astronomer than all the other asteroids put together. The vast majority of the asteroids have their orbits between the paths of Mars

and Jupiter, but this little planet revolves in an orbit so elliptical that at its nearest position to the Earth it comes within the orbit of Mars, and is only $13\frac{1}{2}$ millions of miles from the Earth. It is at times our nearest planetary neighbour, but is so faint that it is never to be seen without the aid of a telescope. It can, however, be photographed, and in this way is of the greatest use to the astronomer. By means of observations on a body so near, its distance, and thus the scale of the whole solar system, is very easily calculated. The little planetoid therefore has supplied astronomers with perhaps the most reliable measurements of the actual scale of the solar system. Since 1898 the discovery of asteroids has gone on at the same rate, but no further objects of interest have been found.

Although the asteroids are, generally speaking, akin to one another, and form a distinct zone in the solar system, they have their own individual differences. Their periods of revolution vary considerably from about three to nine years. Some of the orbits are very elliptical in shape, and, unlike the large planets, many of them do not move almost exactly in the plane of the ecliptic. Pallas, for instance, moves in a path which is inclined to the ecliptic at an angle of thirty-four degrees. In size, also, there are great differences. The four earlier discovered asteroids—Ceres, Pallas, Vesta, and Juno—are the largest. These are the only asteroids which actually show measurable discs and can thus be actually measured, and it is only by the aid of the largest telescopes in the world that such measurement can be made. Ceres is 477 miles in diameter, Pallas 304 miles, Vesta 239 miles, and Juno 120 miles. Vesta is the brightest of the four, so its surface must be highly reflective. The sizes of the

smaller planets have not been measured, but can be estimated, and it is believed that few of them have a greater diameter than twenty-five miles. Practically nothing is known of the physical nature of these minute planets. Professor Barnard observed the four larger ones carefully some years ago with the large telescope of the Lick Observatory, and saw no traces of atmosphere round them. Nothing is known either of their rotation or of the actual condition of their surfaces. Some of them are variable in light, and it is supposed that such variation is caused by the different reflective powers of the different hemispheres, combined with the rotation of the planetoids on their axes. These variable asteroids probably have rugged surfaces on which the amount of light reflected varies considerably.

The asteroid group is one of the most remarkable features in the solar system. It is obvious that one large planet is replaced by many little ones; it is also obvious that the zone divides the two groups of Inner Planets and Outer Planets, and thus separates the solar system into two portions. The existence in the solar system of this group of minute bodies all but innumerable, each pursuing its own appointed path round the orb of day, is another example of the variety and harmony of Nature.

CHAPTER X

JUPITER, THE GIANT PLANET

ONCE in about every thirteen months there reaches the meridian at midnight one of the most brilliant objects in the sky. Rising about sunset in the east, it gradually ascends until it is due south at midnight and in "opposition" to the Sun. For some time after opposition it is the most brilliant object in the night skies, and as such commands the attention of even the most casual of star-gazers. For Jupiter so far outshines all the stars in its vicinity that there can be no doubt in identifying the great planet. It reigns supreme, shining with a steady light, not so soft as that of Venus, but sharper and more sparkling. As Flammarion remarks: "When Jupiter shines among the stars of the silent night, and when our gaze is fixed on him, who would suppose, while admiring this simple luminous point, that it is an enormous and massive globe, weighing over three hundred times more than the planet which we inhabit, and of which the colossal volume exceeds by nearly thirteen hundred times that of the Earth? We have our eyes fixed on him, his light is so vivid that it casts a shadow like that of Venus, but we do not guess the marvellous grandeur of this distant body." Of all the planets Jupiter is the easiest to observe telescopically. The smallest instrument will show that it is a planet with a round disc, and will give us a glimpse of the four satellites of the planet discovered by Galileo in 1610, over three hundred years ago. Great must have been

the delight and wonder of the great Italian astronomer when, pointing his newly constructed telescope to Jupiter for the first time, he beheld the luminous point of light transformed into a flat disc, with four little points of light circling around it. A two-inch telescope gives a very striking view of the planet. On a clear night such an instrument enables us to see on the disc two or three parallel strokes, as it were. This is our first glimpse of the famous belts of Jupiter, which were first discovered after the time of Galileo. It requires a much larger instrument to bring out the principal features of the belts. With a good telescope we may view what an American astronomer thus vividly describes: "Belts of reddish clouds, many thousands of miles across, are stretched along on either side of the equator of the great planet; the equatorial belt itself brilliantly lemon-hued, or sometimes ruddy, is diversified with white globular and balloon-shaped masses, which almost recall the appearance of summer cloud domes hovering over a terrestrial landscape, while towards the poles shadowy expanses of gradually deepening blue or blue-grey suggest the comparative coolness of those regions which lie always under a low Sun." The belts are not permanent markings; they are belts of cloud, and as such are continually changing. Still, they are not so fleeting as the clouds in our own atmosphere. Some of the Jovian features, indeed, are more or less permanent. Chief among these must be mentioned an object known as "the great red spot." It was first noticed by a number of observers in the summer of 1878, and described by them as a pale pinkish, oval spot. In 1879 it became much more prominent. The pinkish hue gave place to brick-red, while the entire object extended 30,000 miles from east

to west, and 7000 from north to south. The area of the spot was no less than 200 million square miles, greater than the area of the entire terrestrial globe. For three years the spot was a brilliant object, the most prominent feature on the globe of Jupiter, lying immediately south of the great equatorial belt of the planet. Then it began to fade, and an observation by Ricco at Palermo in 1883 was thought to be the last. But in a short time it revived and again became the most prominent object on the planet's disc. Again it faded considerably, but it is still visible, a permanent feature of Jupiter's disc.

This marvellous spot has for many years attracted the attention of astronomers all over the world. Many speculations have been made as to its nature, and it is difficult to ascertain the exact cause of the appearance in a cloudy atmosphere of a permanent feature lasting so many years. Mr. W. F. Denning, one of the most devoted observers of the planet, gives as his opinion "that it represents an opening in the atmosphere of Jupiter through which in 1878–82 we saw the dense red vapours of his lower strata, if not his actual surface itself. Its lighter tint in recent years is probably due to the filling in of the cavity by the encroachment of durable clouds in the vicinity." Another remarkable fact in connection with the spot was ascertained by the American astronomer Professor Barnard. "One of the most interesting features of the great spot," he said, "was the repulsion it seemed to exert upon adjacent markings on the planet. For a time it was surrounded by a sea of light that completely encircled it for a distance of three or four thousand miles, and which appeared as a visible barrier against the approach of any spot or marking."

Observations on various spots and belts many years ago revealed the fact that Jupiter rotated on its axis

in a little under ten hours. The most exact determination fixes the rotation period at 9 hours 55 minutes 36·56 seconds. Thus Jupiter's "day" is very much shorter than that of the Earth, notwithstanding the size of the mighty planet. The curious point, however, about the rotation of Jupiter, as ascertained from observations on the red spot and other markings, is that, like the Sun, its rotation is not uniform. According to one astronomer, no fewer than nine different rotation periods are found. There is not much difference, it is true, between the various periods, but this difference gives rise to curious results. Some bright spots round about the equator actually overtake the red spot at the rate of 260 miles an hour. All these facts go to prove that in Jupiter we have a world of a different type from the four inner planets. In the case of Mars, for instance, we see the actual surface of the planet. The markings may change in accordance with the seasons, but they are always to be seen, and the rotation period derived from them is constant and unchanging. In the case of Jupiter we never see the actual surface. A remarkable thick atmosphere enshrouds the planet, an atmosphere quite unlike our own. We cannot compare the Jovian markings to our terrestrial clouds. A cloud on the Earth is a fleeting thing. It does not last for days, still less for thirty-two years. The red spot in Jupiter's atmosphere has been seen since 1878.

It is quite obvious, therefore, that Jupiter is a body of quite a different order from our own world. In many ways it resembles the Sun more than the smaller planets. Indeed, in 1879, Brédikhine of Moscow observed on the Jovian disc a group of "faculæ" similar to those of the Sun. Some astronomers believed that the markings on Jupiter, like those on the Sun, are regulated by an eleven-year period,

but this is not absolutely certain. At all events, observations of Jupiter during the last fifty years have abundantly shown that it resembles the Sun more than the Earth.

It used to be believed that the atmosphere was something similar to our own, but much more dense, and that the cloud belts were analogous to the trade winds on our planet. But the impossibility of this view was long since demonstrated. The clouds on the Earth are raised by Sun heat. Jupiter is at a much greater distance from the Sun than the Earth is, and yet it possesses an atmosphere much more dense and cloudy than ours. The explanation is obvious—Jupiter is very much larger than the Earth; it is a world in a state of chaos, "without form and void"; it is in a condition of great heat, so that the vapours, instead of settling on the surface in the form of oceans, are boiled off the fiery surface, as it were, and kept suspended in the atmosphere in the form of dense cloud masses. Jupiter seems to be in a very primitive condition, somewhat similar to Saturn, and probably Uranus and Neptune, and it throws an interesting sidelight on the previous condition of our own world.

For some time astronomers believed Jupiter to be slightly self-luminous, but this view has not been confirmed. The planet probably gives out an appreciable quantity of heat, but it is likely that its days of shining by its own light are ended. Very probably the surface is only now becoming solidified, and enormous volcanic disturbances are of daily occurrence in the semi-liquid planet. Of course this is but speculation, for the atmosphere is so dense that it is quite impossible to see it. From the surface of the planet—whether it is a solid or a semi-liquid surface—no glimpse of the outer universe is visible. Supposing, however, that an observer on Jupiter could

see through the cloud belts, the Earth would be hardly visible, being only seen with difficulty in the vicinity of the Sun. "At night," says a famous astronomer, "the spectacle of the sky seen from Jupiter is, with reference to the constellations, the same as that which we see from the Earth. There, as here, shine Orion, the Great Bear, Pegasus, Andromeda, Gemini, and all the other constellations, as well as the diamonds of our sky. The 390 millions of miles which separate us from Jupiter in no way alter the celestial perspectives. The most curious spectacle of this sky is unquestionably the spectacle of the four moons." To these moons Jupiter acts as a miniature Sun, giving out an appreciable amount of heat as well as reflecting the heat of the Sun. Jupiter is attended by no fewer than eight satellites, four large and four small. The discovery of the four large satellites was one of the greatest in the history of astronomy. In 1610, Galileo, at Padua, turned the newly-invented telescope on Jupiter, and discovered that the giant planet was surrounded by four satellites. The discovery was hailed with great joy by the supporters of the Copernican system. Here was a miniature of the solar system disclosed by Galileo's telescope, which ought to convince even the most sceptical. But the opponents of the new system would not be convinced, and regarded the discoverer with very unfriendly feelings. One Italian student refused to look through the telescope lest he should see the satellites. Another consented to observe Jupiter, and was immediately convinced that the satellites existed; while a third declared that even though he saw the satellites through the telescope he would not believe in them, declaring that they were in the telescope and not in the sky.

The four satellites are sometimes known by the name

of Io, Europa, Ganymede, and Callisto, though they are more frequently designated by the numerals I., II., III., and IV. The nearest satellite, Io, revolves round Jupiter in 1 day 18 hours 27 minutes, at a mean distance of 261,000 miles. Its diameter measures about 2500 miles. The second satellite, Europa, the smallest of the four, with a diameter of 2100 miles, revolves round the primary in 3 days 13 hours 13 minutes, at a mean distance of 415,000 miles. The third moon, Ganymede, is the largest of the four, its diameter measuring 3550 miles. It is, therefore, larger than the planet Mercury. It moves round Jupiter in 7 days 3 hours 42 minutes, at a mean distance of 664,000 miles. Callisto, the fourth satellite, with a diameter of 2960 miles, revolves round the primary at a mean distance of 1,167,000 miles in 16 days 16 hours 32 minutes.

These satellites are among the easiest objects of observation to the amateur astronomer. The smallest telescopes will show them, and they are a source of never ending pleasure. They may be seen sometimes in transit across the disc of Jupiter, while sometimes we are able to witness their immersion in the shadow of the giant planet and consequent eclipses, while at times we see Jupiter's disc pass over one or more of the satellites and obscure them from view. This phenomenon is known technically as an "occultation."

A small telescope will not show surface markings on the discs of the satellites. Even with the largest and best instruments, astronomers have learned little of the constitution of these moons. As to size, the two largest are of planetary bulk and dimensions. The four satellites combined form one 6000th part of the mass of Jupiter, and their volumes form one 7600th part of the volume of the

giant planet. Hence we see that while three of the satellites are absolutely larger than our Moon, all four are, in comparison to Jupiter's bulk, relatively much smaller bodies. The satellites seen from Jupiter's surface cover an area of the sky larger than the area filled by our Moon, but they are much less brilliantly illuminated, owing to the much greater distance of the Jovian system from the Sun. The total amount of light reflected from all four satellites at once is only one-sixteenth of that reflected by the full Moon as seen from the surface of the Earth.

For over 280 years the system of Jupiter was regarded as complete. The four satellites had been known for a long period, their motions had been carefully calculated; in fact, astronomers were thoroughly acquainted with all the details of the Jovian system. Great was the surprise among astronomers when in September 1892 it was announced that an American astronomer had discovered a fifth satellite. On the ninth of that month Professor Barnard, while observing Jupiter with the great telescope of the Lick Observatory in California, detected a minute speck of light near the planet. A series of observations proved that this was indeed a new satellite of Jupiter, closer to the planet than any of the other moons. It revolves round Jupiter in 11 hours 57 minutes, at a mean distance of 112,000 miles. It is very much smaller than the other satellites, for its diameter is little over a hundred miles.

In 1905 two other satellites of Jupiter were discovered by Professor Perrine at the same Observatory. Both of these minute objects were discovered by the aid of the photographic plate. The sixth satellite revolves round Jupiter in 242 days, at a mean distance of 6,968,000 miles. The seventh satellite is slightly closer to the planet, round which it moves in 200 days, at a mean distance of

6,136,000 miles. Early in 1908 came the announcement of the discovery of another satellite. The eighth moon, also very small and faint, was discovered by Mr. Melotte, assistant at the Royal Observatory, Greenwich, with the aid of photography. It is at a much greater distance from the planet than the other satellites, and revolves round Jupiter in the opposite direction. In astronomical language its motion, instead of being direct, is retrograde. In this respect the most distant satellite of Jupiter resembles the most distant satellite of Saturn, as will be explained in the next chapter. It is quite possible that there may be other satellites still undiscovered.

The system of Jupiter is as interesting as it is beautiful. So far as is known at present, the planet has eight satellites, four of almost planetary dimensions, four of what may be called asteroidal size. The system is more beautiful and complex than Galileo and the earlier astronomers imagined. As to the possibility of life in the Jovian system, the reader will have been able to judge from the physical condition of the planet that no life, akin to life as we know it, can possibly exist at the present moment. That it may be inhabited at some future time when the cloud belts roll away, and the vapours settle on the surface as oceans, is quite possible. Some astronomers believe that the satellites are likely to be inhabited, and certainly the four larger moons seem the more likely bodies in the Jovian system on whose surfaces life may exist. To these moons Jupiter will be a semi-sun radiating, if little or no inherent light, at least a vast amount of inherent heat. But of the actual surfaces of the satellites we know practically nothing. Marvellous and complex as is the system of Jupiter, it is simple compared to that of Saturn, to the consideration of which the next chapter is devoted.

CHAPTER XI

SATURN, THE RINGED WORLD

IN ancient days when astrology had sway over mankind, the planets were believed to influence the destinies of mortals. To be born under the planet Jupiter was to be sure of a career marked by good fortune and distinguished by glory. Mars was the god of war, and those born under the sign of that planet were characterised by martial deeds and military renown. The favourites of Mercury had the arts as their special sphere, while Venus held sway in the realms of love. Saturn was known as the unlucky planet. Its slow motion and its dull leaden light betokened gravity and gloom, and those born under its sign were called "saturnine," and were thought to be dull and morose in their natures, and to be destined to grief and calamity. To the unaided eye Saturn appears as a star of the first magnitude, with none of the brilliancy of the other planets. It has nothing of the steady brilliance of Jupiter, the soft luminosity of Venus, or the fiery red light of Mars. Consequently the ancients thought Saturn by far the least interesting of the planets, and indeed, when it is examined with the unaided eye, we are inclined to accept their opinion. But with a powerful telescope we gain quite a different idea of Saturn. So far from being the least interesting of the planets, it is the most interesting. Indeed, it is absolutely unique in the solar system, and so far as is known, in the Universe.

When we turn the telescope on it we behold a glorious orb. Its disc is striped with belts similar to those of Jupiter, only fainter owing to its greater distance. A wonderful system of three rings surrounds the planet—two bright, and one of a dusky hue. These are perfect in symmetry and exquisite in beauty. Our sense of the marvellous is deepened when it is borne in mind that these rings are not less than 176,000 miles in diameter and 30,000 miles in width, and not more than from fifty to one hundred miles in thickness. Telescopic contemplation of this magnificent planet, with its imposing system of rings, fills the mind with feelings of wonder and awe. As Flammarion puts it: "When we think that there is here a celestial deck on which the entire globe of the Earth might roll like a ball on a road, and that the world poised in the centre is several hundred times larger than our planet, we transport ourselves easily in thought to those sublime regions."

The system of rings which encircle Saturn has been known to astronomers for two and a half centuries. To Galileo they were a source of much perplexity. His telescope was not powerful enough to disclose their true nature. When he first observed Saturn it seemed to him to be oval-shaped, and this appearance he believed to be due to the fact that the planet was in reality triple, consisting of a large central body with a smaller orb on each side, "like two servants who help old Saturn on his way." Accordingly, he announced that the planet was triple. Some time later he concluded that the appearance pointed to the existence not of a triple planet, but of an orb oval in shape. Great was his surprise when two years afterwards he found that the planet had become round again. We now know that these appearances are due to the periodical vanishings of the rings, owing to the fact that as Saturn moves onward in its orbit, we sometimes behold

the ring system, which is very thin, directly in the line of vision, and thus see it edgewise. Galileo knew nothing of this, and he was astonished at the planet's change of shape. He was utterly cast down. Writing to his friend the ambassador of the Grand Duke of Tuscany, in the end of 1612, he said: "Were the appearances indeed illusion or fraud, with which the glasses have so long deceived me as well as many others to whom I have shown them? I do not know what to say in a case so surprising, so unlooked for and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken have greatly confounded me." So much was Galileo disappointed at his failure to solve the problem, that he gave up observing Saturn altogether. It was left to a later astronomer, the Dutchman Huyghens, to demonstrate the true nature of the appearances. With the aid of telescopes much more powerful than those used by Galileo, he came to the conclusion that the planet was surrounded by a ring. But he was not absolutely certain, and he wished to test his theory so that there would be no possibility of mistake. In those days it was the custom of men of science to publish their discoveries to the world in the form of anagrams. That is to say, they wished to secure for themselves the right of discovery and at the same time have the opportunity of confirming their theories. Accordingly he jotted down a number of letters in chaotic form, and published them in an apparently senseless jumble. Huyghens was afraid that while testing his theory of the existence of a ring some other astronomers might make the discovery independently, and thus rob him of the honour. Therefore he published the following anagram in 1656—

"aaaaaaa, ccccc, d, eeeee, g, h, iiiiiii, llll, mm, nnnnnnnnn, oooo, pp, q, rr, s, tttt, uuuuu."

Three years later he arranged the letters in their natural order, having satisfied himself that his theory was correct. This made up the following Latin sentence—"Annulo cingitur tenui plano nusquam cohaerante ad eclipticum inclinato." Translated into English this reads—"The planet is surrounded by a slender flat ring inclined to the ecliptic and nowhere touching the body of the planet." Many years afterwards it was found that the ring was really composed of two rings. We now know of the existence of three; within the two bright rings there is a third known as the dusky ring. It was the last of the three to be discovered, and was first detected in 1850.

For many years it was supposed that the ring system was a solid whole—that the rings were flat planes. But it has been now proved that they are not solid, being made of innumerable small satellites or rather meteorites, and so close together are these minute bodies that they appear from this vast distance as a complete solid. They are in constant revolution round the planet. From Saturn it is probable that they appear as a continuous whole. Indeed, from the surface of the planet the ring-system must seem both magnificent and stupendous.

Let us imagine ourselves on the globe of Saturn on a journey from the pole to the equator, keeping a close watch on the Saturnian heavens. From the poles the rings are invisible. As we move equatorwards, the system gradually comes into view. As we advance, the rings rise higher and higher above the horizon. At the same time they diminish in breadth as we see them more and more foreshortened. At the equator they are exactly overhead, and we only see the interior edge of the system as a narrow arch extending right round the heavens. From a latitude of twenty-eight degrees on Saturn, says the

How Saturn would Appear from its Nearest Satellite

This imaginary illustration, from a drawing by Abbé Moreux, represents Saturn rising in the firmament of the nearest satellites. To these moons the ringed planet is a superb spectacle.

French writer Guillemin, "the ring-system is seen as an immense arch, interrupted by a large space at the summit. The sky is visible through the division which separates the two principal rings, and it again appears below the arch. The interruption at the summit is produced by the shadow cast by Saturn, and it is only distinguished from the sky by the absence of stars. It is possible, however, that this eclipsed portion of the rings may be sometimes rendered visible by the refraction of the solar rays by the atmosphere of the planet. . . . When we add to the strange beauty of the spectacle the presence of the satellites presenting different phases, some full, others new, others gibbous or crescent, an idea will be formed of the variety of aspect of the Saturnian nights."

This description applies only to the summer time of the particular hemisphere of the planet for which it is intended. In winter the ring-system reflects no light whatever to the planet. Not only do the rings give no light during the Saturnian winter, but they cut off the light of the Sun from the planet. They totally eclipse the Sun for long periods at a time. For fifteen years, half of the period of Saturn's revolution, the Sun is to the south of the rings, and for fifteen years to the north, but the shadow of the ring-system is so broad that the regions midway between pole and equator on Saturn have to suffer eclipses which last for more than five of our years at a time. Saturn is at a much greater distance from the Sun than the Earth, and receives much less sunlight; consequently it can ill afford to be deprived for long periods at a time of the little sunshine which is its due. Saturn therefore does not seem a very inviting dwelling-place for human beings.

In all probability, however, there are no inhabitants on

the planet. We learn this from a study of the globe itself. Saturn is the second largest planet in the solar system, and has a diameter of 74,000 miles. Suppose we represent the Earth by a pea; in proportion we may take an orange to represent Saturn. Its distance from the Sun is nearly nine hundred millions of miles, and it requires almost thirty years to revolve once round the central luminary. Like the Earth, Saturn rotates on its axis. This rotation is performed in Saturn's case in 10 hours 16 minutes—a much more rapid rate of rotation than that of our world, notwithstanding the greater size of the ringed planet.

The globe of Saturn, apart from the rings, is a striking spectacle—although not so striking as Jupiter—seen through a good telescope. The cloud belts do not show the same rapidity of change as do those of Jupiter. Still, changes are apparent to the careful observer. The only surface of Saturn which we can see is its atmosphere, which is so dense and cloud-laden that beyond it nothing is visible. On the Earth, and also on Mars and Venus, the atmospheric clouds are raised by the heat of the Sun. Venus, for instance, has a denser atmosphere than our world, probably because it is closer to the Sun. Mars, on the other hand, has a thinner atmosphere. But Saturn is at a much greater distance, and at that distance the heat of the Sun is so diminished in power that it could not be responsible for the existence of an atmosphere so much more cloud-laden than ours. The heat which raises the clouds comes not from the Sun, but from the planet itself. Like Jupiter, Saturn appears to be in a much earlier stage of development than the Earth. The oceans which will at some future date settle down on the planet's surface exist at present only in the form of masses

of cloud floating in the atmosphere. It is more than doubtful whether Saturn has any solid surface beneath the dense canopy of clouds. It may have a crust partly solidified, but subject to violent eruptions, such as seem to have been prevalent during the early stages of the life of our own world. Let us picture to ourselves what goes on beneath those cloud belts. A world in a state of chaos exists there—violent eruptions take place; boiling, seething masses of fire shoot through the partly solidified crust. It is a world of restless turmoil and sweltering heat. This view of the condition of Saturn is confirmed by the fact that while it is about seven hundred times larger than the Earth, it is only ninety times as heavy. Indeed, in proportion to its size, Saturn is the lightest of all the planets. It is only equal in weight to a globe of walnut wood of the same size. In fact, if we could imagine a great ocean large enough to hold the various planets, and if we could imagine the planets thrown one by one into that ocean, Saturn would actually float while all the others would sink. The extraordinary lightness of Saturn is explained by its condition of intense heat.

Thus we see that in two particulars Saturn is unique in the solar system. It is the lightest of all the planets, and it possesses a marvellous system of rings. But in another respect it is also unique. So far as we know, it possesses more satellites than any other planet. There are no fewer than ten of these little bodies owning it allegiance and circling round it in ceaseless revolution. In order of distance from the planet, the names of these little worlds are Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Themis, Japetus, and Phœbe. Of these, Titan is by far the largest. It was the earliest discovered, and was first seen by Huyghens during his

study of the planet. It is about three thousand miles in diameter, and equal in size to the planet Mercury. Indeed Titan is quite a little world in itself. The faintest, and probably the smallest, is Themis, which was discovered in 1905 by Professor W. H. Pickering of Harvard, by means of photography. So faint is the little moon that it is quite invisible by ordinary telescopic methods, and is only known by its image on the photographic plate.

The most remarkable member of the system of Saturn, however, is the little moon known as Phœbe, the most distant of the satellites. All the other nine moons revolve from west to east, the rings also revolve in that direction, the planet likewise rotates in that direction. But Phœbe revolves in the opposite direction—from east to west. Just imagine, if we had a number of moons and one of them revolved in the opposite direction from the others, how complicated and bewildering our evening skies would become.

The satellites have great diversities in their periods of revolution. Little Mimas, the closest to Saturn of the ten, is at a distance of 115,000 miles, and revolves in 22 hours 37 minutes. Phœbe requires sixteen months for its slow revolution round its primary. In the heavens Saturn, with its magnificent system of rings and its gorgeous retinue of moons, is a spectacle as majestic as it is unique. If any of its satellites be inhabited, these inhabitants will probably regard the planet as we regard the Sun—as light giver and heat giver; and with good reason will they look on Saturn as their Sun, as probably it gives out a certain amount of intense heat. Supposing either Saturn or its satellites were inhabited, the inhabitants would be hardly able to catch a glimpse of our Earth. Seen from Saturn, the Earth is a small insignificant point, lost in the light of the far-away luminary, the Sun.

CHAPTER XII

THE BOUNDARIES OF THE SOLAR SYSTEM

SATURN was the most distant world known to the ancients. They regarded its orbit as the boundary of the planetary system, and it was not until the year 1781 that astronomers learned that the solar system extended to a much greater distance than the orbit of Saturn. Of the two distant planets Uranus and Neptune little is known, but the story of their discovery is one of the most interesting chapters in the history of astronomy.

To the genius and skill of William Herschel we owe the discovery of the planet Uranus. The record of this discovery is so bound up with the life-story of the discoverer that it is impossible to separate them. That life-story [1] is a record of endless perseverance, boundless energy, and undying enthusiasm. The most striking of all discoveries, however, was nothing less than that of a new planet revolving beyond the orbit of Saturn—the first new member of the solar system discovered within the memory of man. On March 13, 1781, while observing the stars in the constellation Gemini, he, in his own words, "perceived one that appeared visibly larger than the rest." Comparing it with other stars in the vicinity, and "finding it to be so much larger than either of them, he suspected it to be a comet." For some time it was believed to be one of these objects, but when its orbit had

[1] See the chapter on the "Conquest of the Stars."

been calculated by mathematical astronomers it soon became apparent that, instead of revolving in a very long ellipse as most comets do, it moved in an orbit almost circular. There was no doubt therefore that the German musician had discovered not a comet, but a new planet, and had doubled by this discovery the diameter of the solar system.

The scientific world was amazed at the discovery. It had never even suspected that an unknown orb revolved beyond the orbit of Saturn. It was, however, even more surprising to find that Uranus had often been seen and catalogued as an ordinary star—no fewer, indeed, than seventeen times. Flamsteed, the first Astronomer Royal of England, observed Uranus four times in different positions, and did not notice the difference of place. A French astronomer, Le Monnier, narrowly escaped discovering the planet in 1769, and would certainly have done so but for the careless and slovenly way in which he jotted down his observations.

Herschel proposed to name the new planet "Georgium Sidus" (the Star of George), after his patron George the Third. This title naturally found no favour on the Continent. A French astronomer suggested the name Herschel after the discoverer himself, while Bode of Berlin suggested Uranus, in keeping with the custom of naming the planets after the Greek and Roman divinities. All these names were in use for a considerable time, but at length the name Uranus prevailed, and is now universally adopted.

The discovery of Uranus was a remarkable achievement, but it led to one still more remarkable—the detection of a planet still farther removed from the Sun. After Uranus had been duly recognised as a member

of the Sun's family of planets, its orbit was calculated. In making these calculations astronomers utilised the early observations of Uranus made by the observers who had failed to notice its difference from an ordinary star. The observations were far from useless, for although these observers had failed to make the discovery which was within their grasp, they had measured carefully the positions of their supposed star. This was all that mathematicians needed to enable them to calculate the planet's orbit with a further approach to accuracy. Bouvard, a French astronomer, published tables giving the planet's positions in the future. But as Uranus did not conform to the orbit which had been laid down for it, Bouvard concluded that there must be some mistake in the earlier observations. Accordingly in 1821 he rejected these altogether, and published a new series of tables, utilising only the observations made since Herschel's time. Again, however, the planet was not in the predicted place. The error was very minute, it is true; as the late Miss Clerke points out, "if the theoretical and the real Uranus had been placed side by side in the sky, they would have seemed to the sharpest eye to form a single body." In an exact science like astronomy, however, an error like this is intolerable, and is evidence of some flaw in the theory. Some astronomers began to doubt the universality of the law of gravitation on which all these calculations were founded, and to ask if the law did not break down at the boundaries of the solar system.

Gradually the idea dawned on astronomers that perhaps another planet, at a greater distance from the Sun, was attracting Uranus from the predicted path. The problem was, how could this be tested. It is no easy matter to search through thousands of stars along the zodiacal

constellations to find a planet: such a task would be impossible. The only hope of detecting the planet lay in calculating its position from its influence on Uranus. Here was a mighty problem involving great mathematical powers. One of the greatest calculators of the day resolved to grapple with the question, but he died before the discovery was made. Another astronomer intended to investigate the matter, but found it beyond his powers. At length two investigators in England and France respectively took up the question independently and quite unknown to each other. Adams, a student at the University of Cambridge, noted in his diary in 1841 his resolve to investigate "the irregularities in the motions of Uranus, which are as yet unaccounted for, in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and, if possible, thence to determine the elements of its orbit approximately, which would lead probably to its discovery." In 1843, after taking his degree at Cambridge, he commenced his investigation, which occupied him for two years. On October 21, 1845, he called at Greenwich Observatory, and left a paper containing the elements, position, orbit, &c., of the supposed planet, and approximately fixing its position in the heavens—expecting that the Astronomer Royal of England, Sir George Airy, would institute a search for the body. Airy, however, was not particularly interested in this question; he was above all what may be called a practical astronomer, and he paid little attention to the paper which the young Cambridge graduate left for his consideration. Adams, too, did not seem particularly anxious to have a search instituted, and the result was that his paper remained in obscurity until it was too late. In 1845, Le Verrier, one of the rising astronomers of France,

also undertook to solve the problem, and he also assigned the position in the heavens of the disturbing planet in the constellation Aquarius. Sir George Airy happened to see one of the papers in which Le Verrier had published his conclusions. He was impressed by the fact that the two independent investigators had reached the same result, and accordingly he wrote to the director of the Observatory at Cambridge requesting him to search the region of the heavens to which Adams' calculations pointed. The Cambridge astronomer commenced a search, but he had no star-maps, and had to chart the region of the heavens before he could search for the planet. At length Le Verrier, having completed his investigations, wrote to Encke, director of the Berlin Observatory, requesting him to search for the planet. Encke at once set two of his assistants, D'Arrest and Galle, on the search, with the result that in a few hours, by the aid of some recently published star-maps, Galle perceived, almost exactly in the position indicated by Le Verrier, a strange star, which was soon identified as the disturber of the motions of Uranus.

Thus was the great discovery accomplished, and another planet added to the solar system. The name of the newly found celestial object was more easily settled than that of Herschel's planet. The following extract from the reminiscences of Sir Henry Holland, the well-known physician, tells us of the naming of this distant world. After referring to his visits to foreign Observatories, undertaken owing to his great interest in astronomy, he says: "That which most strongly clings to my memory is an evening I passed with Encke and Galle in the Observatory of Berlin, some ten or twelve days after the discovery of the planet on this very spot; and when

every night's observations of its motions had still an especial value in denoting the elements of its orbit. I had casually heard of the discovery at Bremen, and lost no time in hurrying on to Berlin. The night in question was one of floating clouds, gradually growing into cumuli, and hour after hour passed away without sight of the planet which had just come to our knowledge by so wonderful a method of predictive research. Frustrated in this main point, it was some consolation to stay and converse with Encke in his own Observatory, one signalised by so many discoveries, the stillness and darkness of the place broken only by the ticking of the astronomical clock, which as the unfailing interpreter of the celestial times and motions, has a sort of living existence to the astronomer. Among other things discussed while thus sitting together in a sort of tremulous impatience was the name to be given to the new planet. Encke told me he had thought of Vulcan, but deemed it right to remit the choice to Le Verrier, then supposed the sole indicator of the planet and its place in the heavens, adding that he expected Le Verrier's answer by the first post. Not an hour had elapsed before a knock at the door of the Observatory announced the letter expected. Encke read it aloud, and, coming to the passage where Le Verrier proposed the name of 'Neptune,' exclaimed '*So lass den namen Neptun sein.*' It was a midnight scene not easily to be forgotten. A royal baptism, with its long array of titles, would ill compare with this simple naming of the remote and solitary planet thus wonderfully discovered."

Thus closes the record of a remarkable discovery—perhaps the most remarkable ever made in astronomy. The discovery of Neptune was not only a magnificent attack on the secrets of Nature, but a glorious triumph

UNFOUNDED FEAR OF THE CHINESE AT THE GREAT COMET OF JANUARY, 1910

This plate shows an excited crowd endeavouring to "frighten away" the comet by means of bonfires and burning torches.

of the human intellect. The honour of the discovery is now given equally to Adams and Le Verrier, although for some time controversy raged as to which of the two deserved most glory. If Le Verrier's results were slightly more accurate than those of Adams, the latter investigator was earlier with his calculations. In this chapter much space has been given to the history of these two discoveries. In the case of the well-known planets, we know nothing of their discovery, but we have considerable knowledge of their physical condition. In the case of the distant worlds we know practically nothing of their physical condition, while the story of the two discoveries, the second the outcome of the first, forms one of the most fascinating chapters in the history of science.

Dusky bands, resembling those of Jupiter, were noticed on the disc of Uranus in 1883 by the late Professor Young. Some astronomers consider that the planet rotates on its axis in about ten hours, but this has not been confirmed by other observers. However, various facts tend to show that its period of rotation must be short. Uranus, so far as is known, is in a condition of great heat. The spectroscope has shown that free hydrogen exists in the Uranian atmosphere, and this indicates the existence of a temperature high enough to separate water into its constituent elements. Observations at the Lowell Observatory a few years ago indicated the existence in the planet's atmosphere of the element helium.

Uranus has four satellites, known as Ariel, Umbriel, Titania, and Oberon. Of these the two last named were discovered by Sir William Herschel in 1787. Ariel was glimpsed by the astronomer Lassell on 14th September 1847, and Umbriel by Otto Struve a few weeks later,

their existence being finally confirmed by Lassell's observations a few years later. The satellites are very faint. Ariel, the nearest satellite, revolves round Uranus in 2 days 12 hours, at a mean distance of 124,000 miles. Umbriel revolves in 4 days 3 hours, at a mean distance of 173,000 miles. Titania, at a mean distance of 285,000 miles, revolves in 8 days 16 hours; while Oberon, at a mean distance of 381,000 miles, requires 13 days 11 hours to circle round its primary. Nothing is known of the physical condition of these satellites. A remarkable fact connected with them is that they revolve almost at right angles to the plane of the ecliptic, in which most of the planets and satellites move. It is quite possible that there may be other satellites of Uranus yet undiscovered.

If little is known of Uranus, less is known of Neptune; the two worlds are about the same size, and seem to have many points in common. The spectrum of Neptune has been investigated by various observers, who have found it to resemble closely that of Uranus. In 1883, Mr. Maxwell Hall, an astronomer in Jamaica, noticed certain variations of brightness, which he believed indicated that the planet rotated on its axis in about 8 hours, but this observation has not been confirmed. Neptune has one satellite, so far as is known. It was discovered by Lassell on 10th October 1846—only a fortnight after the planet itself was detected. It is situated at a distance of 223,000 miles from its primary, round which it moves in 5 days 21 hours 8 minutes. Like the Uranian moons, its motion is retrograde. It must be very large to be visible at all at a distance so vast. Some astronomers consider that it is the largest satellite in the solar system. Probably it is over three thousand miles in diameter.

We have now described the outermost planet of the

solar system, revolving in solitary loneliness. But is the orbit of Neptune really the frontier of the Sun's domain? Are there planets beyond Neptune? Astronomical science has not yet answered these questions. The existence of one planet at least has been strongly suspected, and at the present time (1910), Professor W. H. Pickering is undertaking a search for a world beyond Neptune, the existence of which he believes to be indicated by its influence on the motion of certain comets. It may, however, be many years before such a planet, if it exists, is detected.

We have now come to the end of a description of the solar system, proceeding outwards from the Sun. But the planets and their satellites are not the only bodies in the solar system. There exists another class of celestial objects—the cometary and meteoric bodies. To the consideration of these the next few chapters will be devoted.

CHAPTER XIII

THE SUN'S FAMILY OF COMETS

OF all the celestial bodies, perhaps comets are the most remarkable and the most mysterious. They are totally unlike the planets; instead of being round solid globes, they seem to be diffused masses. Instead of revolving round the sun in orbits nearly circular, those comets which have been proved to belong to the solar system move in enormously long ellipses, and are only seen for a brief period when in the vicinity of the Sun and the Earth.

Among the ancients, and indeed in the Middle Ages, comets were a source of terror to mankind, and were regarded as terrible portents of wars, famines, deaths of kings, and other national calamities. A bright comet which appeared in 1066 was supposed to be a portent of the Norman Conquest of England. Another which was seen in 1456 was believed to be connected with the taking of Constantinople by the Turks. In the Middle Ages, it has been remarked, every comet "was believed to be a ball of fire flung from the right hand of an angry God," and this view was by no means confined to the ignorant. We find Martin Luther and John Knox firmly believing in the direful effects of comets on the Earth and its inhabitants. In the seventeenth century an illness among cats in Germany was actually ascribed to the appearance of a comet. In our time, thanks to the advance of science, we know that comets have no effect

whatever on the Earth, either baneful or beneficial. Consequently terror at brilliant comets has given way to wonder and admiration.

A bright comet may be said to consist of three parts—coma, nucleus, and tail—while faint comets only seen in telescopes generally lack the tail. To the ordinary star-gazer a comet is an object with a tail; but, as a matter of fact, comets with tails are far outnumbered by comets without tails—little comets which are only seen with the aid of the telescope, and which were consequently unknown to the ancient astronomers. Some comets not only lack a tail, but are also wanting in coma and appear like round diffused planetary discs. As was seen in previous chapters, the planet Uranus was at first believed by Herschel to be a telescopic comet, and Ceres, the first discovered of the asteroids, was also taken for a comet. When a comet is first seen in a powerful telescope, or first imprints its image on a photographic plate, it is merely a round faint nebulosity. As it approaches the Sun, if it is going to be a prominent comet, it develops the well-known tail or tails, for comets have been known with two, three, and as many as six tails.

Comets are of two kinds—those which belong to the solar system, and those which do not, and in this chapter attention is given to the former class. The scientific study of comets only began about the year 1680, when Sir Isaac Newton, in his investigation of them, demonstrated that they were, like the planetary bodies, subject to the action of the law of gravitation. Newton himself did not prove that any particular comet revolved round the Sun. This was reserved for his friend Halley, who in 1705 stated his conclusions on the subject.

Of all the comets which have been seen by the

Earth's inhabitants, the most famous is that which bears Halley's name. It was not the brightest seen, nor the most remarkable; but it was the first which was definitely proved to revolve round the Sun. There have been brighter comets, such as Donati's, and the great comet of 1811; but the chief interest in Halley's Comet lies in its regular returns at intervals of seventy-three or seventy-four years.

In the year 1682, while Newton was busily engaged in testing his law of gravitation, a bright comet made its appearance, and was attentively studied by the foremost astronomers of the day. Among these was Edmund Halley, the well-known Englishman, who became the second Astronomer Royal of England. It occurred to Halley that comets possibly revolved round the Sun in orbits similar to those of the planets, and that it would be useful to investigate as to whether a comet had been seen more than once. As Sir Robert Ball says: "At the expense of much labour, he laid down the paths pursued by twenty-four of these bodies which had appeared between 1337 and 1698. Amongst them he noticed three which followed tracks so closely resembling each other that he was led to conclude that the so-called three comets could only have been three different appearances of the same body." The first of these three comets had been seen in 1531, while the second was observed by Kepler in 1607, and the third was the bright comet studied by Halley himself in 1682. The astronomer also noticed that bright comets had been seen in 1456, seventy-five years before 1531, in 1380, and also in 1305, at intervals of about seventy-six years. After a careful study of the comet's orbit, and of the effect which Jupiter would have in retarding the return,

Halley predicted that the comet would reappear in the end of 1758 or the beginning of 1759. He knew that he himself would be dead long before its return, and he wrote thus:—"If it should return according to our predictions, about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." Posterity has not refused to admit this fact, and the name of Halley has ever since been associated with the comet. The verification of his prophecy reflects a glory on his name which will cause it to live for ever among the greatest of astronomers.

As the year 1758 drew near, great excitement prevailed among men of science to see whether Halley's prediction would be fulfilled. The astronomer had been dead for sixteen years, but nevertheless interest in his prophecy was unabated. The French mathematician Clairaut, and two other mathematicians, undertook the task of calculating the exact date of the comet's return. The outcome of these researches was to show that the attraction of Saturn would delay the return of the comet by 100 days and that of Jupiter by 518 days. Men of science all over the world watched anxiously, and at last on Christmas Day, 1758, the comet was sighted by an amateur, a farmer in Saxony. The comet reached its perihelion, or point nearest to the Sun, on March 12, 1759, and then disappeared on its long journey. In 1835 the comet again reappeared, and on November 15, 1835, passed the point of its path closest to the Sun. Three able mathematical astronomers undertook to calculate the exact date of the planet's perihelion passage. Damoiseau, a Frenchman, fixed on November 4, 1835; Pontécoulant, another Frenchman, fixed on November 12; Rosenberger, a German calculator, taking account of the

attractions of all the principal planets, fixed on November 11. The perihelion passage actually took place on November 15—a proof of the remarkable accuracy of the three calculators. In 1835 the comet was first detected at Rome, and was particularly studied by Sir John Herschel, who, on May 5, 1836, caught the last glimpse of the comet with his giant telescope. From 1836 to 1873 the comet was on its journey outward to the most remote point of its orbit, beyond the pathway of Neptune. In 1873 it reached its aphelion, as this farthest point is called, and then commenced returning with increasing velocity to the regions of light and heat.

In November 1908, plates were exposed in the region of the heavens where it was calculated that the comet would appear, but it was not until September 1909 that it was actually discovered photographically by Dr. Max Wolf of Heidelberg. The comet in May 1910 was disappointing as a spectacular object to observers in Britain; but the public interest was unprecedented. Halley's was thus the first comet which was proved to revolve round the Sun in an elliptic orbit, and to be subject to the law of gravitation just as the planets are. Also, of all the known periodic comets, it is the one which has the longest period of revolution.

The next comet ascertained to be also periodic, and to be a member of the Sun's family, was an insignificant little object known as Encke's Comet. On November 26, 1818, Pons, a French astronomer who devoted much of his attention to the discovery of these objects, detected a small telescopic comet. The German astronomer Encke undertook to calculate the orbit of the comet, and found it to be probably identical with comets discovered by the French astronomer Mechain in 1786, by Caroline Herschel

in 1795, and by Thulis in 1805. Encke accordingly found that the time required for the comet to revolve round the Sun was three years and a half, and he calculated that the comet would pass its perihelion point on May 24, 1822. True to Encke's prediction, the comet returned, and the perihelion passage took place within three hours of the time which he predicted. As the late Miss Clerke has remarked: "The importance of this event will be better understood when it is remembered that it was only the second instance of the recognised return of a comet; and that it, moreover, establishes the existence of a new class of bodies distinguished as comets of short period."

The comet returned again in 1825, and has returned ever since at regular intervals. At its return in 1828, it was actually visible to the unaided eye as a star of the fifth magnitude. In 1838 Encke made a remarkable discovery in connection with his comet. He found that it returned to its perihelion point two and a half hours before the predicted time. He accordingly put forward the theory that this acceleration of the motion of the comet was due to the existence of what he called a "resisting medium" in the vicinity of the Sun, too rarefied to retard the motions of the planets, but quite dense enough to make the path of the comet smaller, and eventually to precipitate it on the Sun. This theory was held for a considerable time, but in 1868 the acceleration began to decrease, and accordingly the theory was abandoned. At its return in 1904, the comet was well observed, being comparatively bright. In 1908, however, it was very faint, and the only record of its return in that year was its image on a photographic plate.

Mr. G. F. Chambers, in his book "The Story of the

Comets," gives the number of known short-period comets as thirteen. The periods of revolution vary from over three years in the case of Encke's Comet to over thirteen in the case of Brorsen's. It would require considerable space to describe each of these objects individually. Only some of the more prominent can be mentioned here. In 1843, Faye, at the Paris Observatory, discovered a comet which was ascertained to revolve round the Sun in an elliptic orbit in over seven years. Its orbit is the least elliptic of all the short-period comets. It was last seen at its return in 1895, being missed when it reached its perihelion in 1903. In 1884, Dr. Max Wolf discovered, at Heidelberg, a telescopic comet which was proved to revolve round the Sun in six years and three-quarters. Before 1875, it is doubtful if the comet was a permanent member of our system, as in that year its orbit was completely changed by the great attractive power of Jupiter.

Another remarkable comet was detected in 1892 by Mr. Holmes, an English amateur. Of this comet Professor Barnard, who carefully studied it with the great telescope of the Lick Observatory, wrote as follows:— "From several points of view it was one of the most remarkable comets ever observed. At the time of discovery, it was distinctly visible to the naked eye as a slightly ill-defined star of the sixth magnitude. The remarkable fact that the comet had attained naked-eye visibility when discovered, coupled with the further fact that this region must have been repeatedly swept over by comet-seekers to within a few days of its discovery, shows that the comet must have rather suddenly attained its conspicuous visibility." The orbit of Holmes' Comet is almost circular.

Another well-known comet is that known as Brooks' Second Periodic Comet. It was detected in 1889, and returned again to perihelion in 1896. In 1903 it was again observed much fainter than before. Mr. Chambers remarks in connection with this comet: "The steady diminution in the brightness is so marked that it is hazardous to predict its future. At its last return it was only visible in some of our largest telescopes. It is due to return in 1910, and again in 1917. Shall we see it? Perhaps we shall; perhaps we shall not. But if we do see it on either of these two occasions, it will still be leading a threatened life, for in 1921 it will again approach very close to Jupiter, and very likely that may end its career; or if not, it will certainly lead to a serious transformation of its orbit."

Besides these comets of short period, there are six comets of long period: Westphal's, revolving round the Sun in sixty-seven years, and which is again due in 1913; Pons' Comet, revolving in seventy years, which returned in 1883, and is again due in 1955; Di Vico's, revolving in seventy-three years, which is due in 1919; Olbers', revolving in seventy-four years, which, first seen in 1815, returned in 1887, and is again due in 1960; Brorsen's, with a period of almost seventy-five years, which is due in 1922; and finally, Halley's, already referred to.

Thus it is known that the solar system contains certainly thirteen comets of short period, and six of long period. Besides, it is believed that fourteen other comets are also periodic. Their periods range from five to nine years, but they have not been proved beyond a doubt to belong to the solar system. Besides these periodic comets there are three, Lexell's Comet, Di Vico's Comet, and Biela's Comet, which were once periodic, and

have now either ceased to exist or have been deflected into new paths.

The first named was discovered by Messier, a famous discoverer of comets, on June 14, 1770. An orbit was calculated for it by a Russian mathematician named Lexell, who assigned to it a period of five and a half years. It was, however, never seen again. Lexell found that in 1707 the comet had passed very close to Jupiter, which had completely altered its path; and accordingly he made another calculation, to the effect that the comet should be seen in 1781, but again he was doomed to disappointment. He finally concluded that, in 1779, Jupiter had again altered the comet's path by its enormous attraction when the flimsy cometary body again passed near to the giant planet. Lexell's Comet has never since been seen.

In 1844 a comet was detected at Rome by Di Vico, and an orbit was assigned of 1993 days. The comet, however, was never seen again. The most remarkable case of all was that of Biela's Comet, which, after being known for years as a member of the Sun's comet family, disappeared in 1852, and was not again seen. In a future chapter this comet, which is the key to our knowledge of the nature of these bodies, will be fully discussed.

The comets above mentioned are those which belong to the Sun's system. The great majority of comets with which the next chapter deals have not been proved to belong to our system, and many of them seem to be only visitors from the depths of space.

CHAPTER XIV

THE MESSENGERS OF SPACE

THE previous chapter dealt with those comets which are known to belong to the solar system, and which are thus always subject to the influence of the Sun. In the present chapter attention is directed to the large comets, which are either visitors to the solar system from the depths of space or which, if they do revolve round the Sun, move out to distances so enormous that we cannot with certainty pronounce them to be members of the Sun's family. Many of the most famous comets which have ever appeared belong to these two classes.

Some of the comets contained in the second class probably belong to the solar system, but their periods are so long that astronomers do not know whether or not they will ever return. For instance, the second comet of 1824 has been calculated to have a period of millions of years, the first comet of 1863 has been said to revolve in nearly two million years, the comet of 1680 in over fifteen thousand years, and so on; but no one can implicitly trust these estimates, as much uncertainty surrounds them. Such comets might, in their long journey in space, be attracted from their paths by dark stars or meteor streams, and would thus be lost for ever to the solar system. They cannot be regarded as permanent members of the solar system.

Most of the really grand comets which have been seen—with the exception of Halley's Comet at its appear-

ances—have belonged to either of these two classes. The comet of 1264, a magnificent object which was supposed to have been identical with the comet of 1556, was expected on this supposition to return about 1858. But it was not seen again, and consequently it is doubtful if the two comets were really identical. In 1264 popular superstition fixed on the comet as a presage of the death of Pope Urban IV.

A remarkable comet, known as De Chéseaux's Comet, appeared in 1744. It had no fewer than six tails. De Chéseaux, the discoverer, has left a very detailed description of the object. He wrote as follows:—"The sky was quite overcast from the first to the seventh of March, but on the last-named day the clouds became broken and gave us some hope of seeing the comet's tail. I prepared myself for seeing over again just about what I had seen during the closing days of February. At four o'clock on the morning of March 8th, I went downstairs with a friend into the garden, with the east facing us. This friend, walking in front of me, startled me by saying that instead of two tails there were five. I hardly believed him, but after having passed from behind several buildings which had partly concealed the eastern horizon from me, I did indeed see five tails. . . . Besides these five tails, there was a sixth." This was probably one of the most remarkable comets ever witnessed.

The great comet of 1811 was in many ways unique. Discovered on 26th March 1811, it was last seen on August 17, 1812, nearly seventeen months later. The tail, when seen at its best in the middle of October, stretched into space for the distance of a hundred million miles, while its breadth was fifteen millions. Measurements made by Herschel indicated that the diameter of

HALLEY'S COMET, 1910

To the ordinary observer this comet has proved a failure as a popular spectacle. But as seen through a powerful telescope it has been far from disappointing. This illustration has been made from a drawing at Greenwich Observatory. It represents the aigrette or fan spreading forward from the nucleus in the direction of the comet's motion.

the nucleus of the comet was 428 miles. A famous German astronomer calculated its orbit, and estimated that its greatest distance is fourteen times that of Neptune, and its period over three thousand years.

Another magnificent comet appeared in 1843. This was described as "a grand and wonderful sight for the extraordinary distance of one-third of the heavens, the nucleus being perhaps about the size of the planet Venus." This remarkable comet, one of the brightest which has ever been seen, was detected in the end of February 1843, in the southern hemisphere. After the middle of March the comet became visible in the northern hemisphere. The remarkable feature about the comet of 1843 was its near approach to the Sun. Its central portion was within 78,000 miles of the orb of day, so that only a little over thirty thousand miles separated the surface of the Sun and the comet. The result of this near approach was that the comet whirled past its perihelion point at the amazing rate of 366 miles per second. In two hours and eleven minutes it described half of the curvature of its oval-shaped orbit, while, as one astronomical writer has pointed out, "in travelling over the remaining half, many hundreds of sluggish years will doubtless be consumed." In many ways the comet of 1843 was a remarkable object. Its tail streamed into space for two hundred millions of miles.

The next brilliant comet was detected by Donati at Florence on June 2, 1858, as a little round nebulous mass, very faint, in the constellation Leo, and is considered by most astronomers to have been the grandest comet of the nineteenth century. At first no one suspected that the faint little telescopic object would develop into so magnificent a stellar spectacle as the comet of Donati. In the middle of July a nucleus de-

veloped. In the middle of August a tail began to make its appearance, and by the beginning of September it was visible to the unaided eye. By the twelfth of that month, the nucleus of the comet shone with a brilliance equal to that of the Pole Star. From this date a magnificent celestial spectacle was assured. Occupying a favourable position in the northern heavens, it was in a most famous position for observation. "This comet," as Mr. G. F. Chambers has pointed out, "has not often been equalled in the intense brilliance of its nucleus, and the unusual and, so to speak, artistic configuration of its tail, which features the absence of the Moon in the early part of October, enabled spectators to view to the very best advantage. The passage of the comet in front of Arcturus on October 5th will ever remain treasured in the memory of those who saw it." The late Miss Clerke confirms this estimate; she says: "The most striking view was presented on October 5th, when the brilliant star Arcturus became involved in the brightest part of the tail, and during many hours contributed, its lustre undiminished by the interposed nebulous screen, to heighten the grandeur of the most majestic celestial spectacle of which living memories retain the impress."

The comet was followed by astronomers until March 4, 1859, when it disappeared from the view of the largest telescopes then in existence. Various estimates have been made of the period, such as 1879 years and 2040 years and 2138 years. One calculation suggested that Donati's Comet was identical with a famous comet which appeared in 146 B.C. and is mentioned in the Chinese annals. But the periods calculated are very uncertain. Estimates, probably correct, have been made of the dimensions of the nucleus and tail of the comet. The tail was 14,000,000 miles

long on 30th August, and seems to have reached its maximum length on 10th October, when it streamed outwards into space for 51,000,000 miles. On the same day the nucleus was estimated as 630 miles in diameter. The comet was carefully studied by astronomers on both sides of the Atlantic. Good weather prevailed during its nearest approach to the earth, and consequently it was thoroughly and exhaustively studied.

Three years later another brilliant object, perhaps even more remarkable than Donati's Comet, became visible to the Earth's inhabitants. It was discovered on May 13, 1861, in New South Wales, and on 11th June passed its perihelion point. On 29th June it became visible in the northern hemisphere. The following description was given by Sir John Herschel, who observed it from Hawkhurst, in Kent: "The comet, which was first observed here on Saturday night, June 29th, by a resident in the village of Hawkhurst, became conspicuously visible on the 30th, when I first observed it. It then far exceeded in brightness any comet I have before observed, those of 1811 and the recent splendid one not excepted. Its total light certainly far surpassed that of any fixed star or planet, except perhaps Venus at its maximum."

The remarkable fact about the great comet was that on the night of 30th June, the Earth and Moon passed through its tail. The comet was at the time between the Earth and the Sun, fourteen millions of miles from our planet, while its tail stretched outwards for fifteen millions of miles. The passage of the Earth through this tail was almost imperceptible. The vast majority of persons never knew that such an event had taken place, and even the astronomers noted only a singular phosphorescence in the sky. Lowe, a meteorologist of the day, remarked

that the sky had a yellow auroral aspect, and that the Sun gave but feeble light although the sky was cloudless, and at seven o'clock in the evening, although it was the midsummer season, artificial lights had to be used. The fact that our world passed through its tail and that the inhabitants were unaware of the fact, is the strongest proof of the harmlessness of this large comet.

The comet of 1874 discovered by a French astronomer named Coggia, at Marseilles, on 17th April 1874, and since known by his name, was much less brilliant than its predecessor in 1861, but nevertheless was a fine celestial spectacle. In July it became visible to the unaided eye. On the 21st of that month it was at its nearest point to the Earth, a distance of nine millions of miles. Various estimates have been made of the period in which the comet revolves. One calculation assigned a period of 5711 years, and another a period of 10,455 years.

The comet of 1880, seen in the southern hemisphere only, was one of the most remarkable cometary bodies. In appearance it was very similar to the great comet of 1843, and when its orbit was calculated it was found to revolve in a path almost identical with that famous body. Three of the most distinguished calculators investigated the comet's motions independently, and each found the path of the two bodies almost identical. Two years later another great comet was discovered by the director of the Observatory at Rio de Janeiro. It soon became a magnificent object in the southern hemisphere. Sir David Gill, who observed it from the Cape Observatory, remarked that the comet "showed an astonishing brilliancy as it rose behind the mountains to the east of Table Bay, and seemed in no way diminished in brightness when the Sun rose a few minutes afterwards. It was only necessary

to shade the eye from direct sunlight with the hand at arm's length to see the comet with its brilliant white nucleus and dense white sharply bordered tail of quite half a degree in length." The comet passed between the Earth and the Sun on the 17th September, and on the following day was visible in full sunlight close to the orb of day. In Spain it was seen through a passing cloud when very close to the Sun.

The most remarkable feature of this great comet was the fact that its orbit showed a remarkable resemblance to the great comets of 1843 and 1880. Astronomers were amazed at this discovery. It was at least possible that the comet of 1880 was a return of that of 1843; but for an enormous comet to return in only two years was unthinkable. As the late Miss Clerke remarked, "A comet which at a single passage through the Sun's atmosphere encountered sufficient resistance to shorten its period from thirty-seven to two years and eight months must in the immediate future be brought to rest on his surface." The great comet was kept under observation for about six months, but before it disappeared the opinion was widespread that it was not a return of the comets of 1843 and 1880. In 1887 another comet was discovered with an orbit also similar. Now the only explanation of the identity of these orbits is that each of these comets were fragments of a larger cometary body which, revolving in the same orbit, had been gradually disrupted into a number of different comets—the comets of 1668, 1843, 1880, 1882, 1887, and probably also another comet, seen in 1382. This is proof that comets, unlike the planets, are not lasting—that they are liable to be dissipated into space. This much may be gathered from a study of the movements and orbits of comets.

Much more remarkable, however, is the information gained by a study of their physical conditions.

After 1882 no very brilliant comet was visible in the northern hemisphere, although in 1901 another bright southern comet was observed. In 1902, Perrine's Comet was faintly visible to the unaided eye, but too faintly to attract popular attention. The appearance of the great daylight comet of 1910 came therefore as a pleasant surprise not only to astronomers, but also to the general public. On January 15, 1910, the Johannesburg newspaper, *The Leader*, informed Mr. Innes, director of the Transvaal Observatory, that they had received the following telegram from the station-master at the railway station at Kopjes, in the Orange Colony: "Halley's Comet was seen by Fireman Bourke, Driver Tucker, and Guard Marais at 4.45 rising in front of the sun. It was visible for about twenty minutes."

"The railway employees had seen the brilliant object in the sunrise before the astronomers saw it, and they thought it was Halley's Comet, which was due to return at that time. As soon as the comet was observed, however, it was seen that it could not be Halley's. Warned by this message from the station-master, we kept watch on the next morning, but it was cloudy. This morning (January 17) was also cloudy, but there was a break just above the place of sunrise. At 5.29 standard time the comet was seen."

In a later statement Mr. Innes said: "The earliest date on which this comet was seen in South Africa appears to be on Thursday, January 12, at 14 hours 25 minutes Greenwich meantime, by some workmen at the Transvaal Premier Diamond Mine. A letter from Cullinan, dated January 16, informed me that on that date and also on Friday morning several workmen observed the comet."

The comet soon passed the Sun, and became visible

in the evening skies—a magnificent object, which attracted much attention; and had it not been for the unfavourable weather in Great Britain at the time, a good deal more would have been seen of it. On the clear evenings the comet was observed and admired by the average man and closely studied by the astronomer. The comet was observed by the present writer at Balerno, Mid-Lothian, on January 22 and 29, observations on other dates being impossible owing to the unfavourable weather. Seen in a two-inch refractor on January 29, the nucleus was very bright and well defined, while the head presented a resemblance to drawings of Coggia's Comet of 1874.

Even at the large Observatories it was difficult to get good photographs, owing to its position in the western sky so close to the sunset twilight. The spectrum of the comet was observed by Professor Frost, director of the Yerkes Observatory, on January 24, when the bright lines of sodium characteristic of many comets were noted. Cyanogen was also detected. The spectroscopic observations indicated that on January 27 the comet was receding from the Earth with a considerable velocity. This agrees with its very rapid diminution in brightness. On January 29 it was well seen; a few days later it was practically invisible.

CHAPTER XV

THE NATURE OF COMETS

IN the two previous chapters mention was made of the two principal classes of comets—comets which have been proved to belong to the solar system, and those comets which either belong to our system, revolving in uncertain periods, or only pay a fleeting visit to the planetary regions, dashing away again into space. Although these two classes differ in many respects, they only differ in regard to their orbits. That is to say, all comets, whether they belong to the solar system or not, are alike in their constitution and nature; and in this chapter an attempt will be made to explain the complicated phenomena connected with them.

The most striking feature about a bright comet is its tail. As remarked in a previous chapter, telescopic comets are often devoid of tails, but all bright comets are distinguished by these appendages, and consequently, to the average man and the casual star-gazer, a comet is only of interest if it possesses a tail. One of the most notable things about the tails of comets is that they are always pointed away from the Sun. If the comet is approaching the Sun, the tail follows the head. If it is receding from the Sun, the head follows the tail. This is a remarkable fact, which shows that comets lack the stability which characterises the planets. For many years this fact puzzled astronomers, and it was not until the beginning of last century that any progress was made

towards an explanation. The astronomer Olbers, of Bremen, well known for his discovery of the asteroids, explained the tails of comets very simply. The Sun not only attracts comets and planets to itself, but its light exercises a repulsive power on minute particles, which are thus driven off in a direction opposite to the Sun. This theory was very fully elaborated by a famous Russian astronomer, the late Professor Brédikhine. Brédikhine's researches led him to divide the tails of comets into three types. The first of these consists of long straight tails, pointed directly away from the Sun, represented by the tails of the comets of 1811, 1843, and 1861. In the second of these types, represented by those comets bearing the names of Donati and Coggia, the tails, although on the whole pointed away from the Sun, are considerably curved. The tails of the third type have been described as "short, strongly bent, brush-like emanations," which in bright comets "seem to be only found in combination with tails of the higher classes." He showed that, probably, tails of the first types are formed of hydrogen, those of the second of hydrocarbon, and those of the third of iron, with a mixture of sodium and some other elements.

On the whole, this theory is considered satisfactory. The question, however, presents itself,—What is this remarkable repulsive force? There seems to be a general agreement among the scientists that the force is electrical. It only affects the very smallest and most insignificant particles of matter, and this explains why the planets and solid bodies are not affected by the force. It has also been suggested that the repelling force may be due to what is called "light pressure," the action of rays of light on very minute particles of matter.

So much has been learned of the nature of comets by

theory. Most of our knowledge of these objects, however, is due to direct observation. The invention of the spectroscope, about the middle of the nineteenth century, referred to in a previous chapter, resulted in a considerable increase of our knowledge of comets and cometary phenomena. It was shown early in the history of this line of research, by Donati and others, that the light of comets is partly inherent and partly reflected. The late Sir William Huggins, the late Dr. Copeland, and others, ascertained the existence in the heads of comets of hydrocarbon gas, and this has been since confirmed by other observers. These observations, of course, give support to Brédikhine's theory of comets' tails. In 1882 this theory was still further confirmed by observations which the late Dr. Copeland and others made of Wells' Comet of that year. On May 27th, Copeland ascertained the existence of sodium in the comet. This was the first occasion on which that element was recognised in one of these bodies. The same astronomer also recognised sodium in the great comet of 1882.

A comet which contributed materially to our knowledge of cometary phenomena was that discovered on September 1, 1908, by Morehouse, an American astronomer. Observations on this object revealed the presence of the poisonous gas, cyanogen, which was indeed the most prominent element in the comet, and which dominated its spectrum. Other remarkable disclosures were made by this comet. A large number of photographs were taken at the Goodsell Observatory, Minnesota. Professor H. C. Wilson, of that institution, remarks as follows on this comet: "While the observer was guiding the telescope for these photographs, the portion of the comet's tail which was in the field of the guiding telescope grew visibly fainter, and appeared to

detach itself from the head. The two photographs taken with the six-inch camera show that this appearance was real, and that the bright part of the tail was actually detached from the head of the comet and was moving outward." On October 15, a bend became apparent in the main tail, which photographs showed to be travelling rapidly from the head. "This outward motion," says one observer, "was also traceable in the case of several knots of brightness in the tail."

Morehouse's was not the only comet which was observed to break up. The great comet of 1882 was also seen to throw off portions of its mass. A German astronomer noted on 5th and 7th October of that year two centres of condensations in the comet, while on the 9th of the same month Schmidt detected a little nebulous object close to the comet, which had been apparently thrown off. Professor Barnard, some days later, glimpsed six or eight little cometary masses separate from the comet. Another instance of cometary disruption was afforded by Brooks' Second Periodic Comet, discovered in 1889. About a month after its discovery, it was seen to have thrown off four fragments. In his interesting work on comets, Mr. Chambers writes as follows:—"Two of these were very faint and soon disappeared, but the other two brighter ones were miniatures of the main body, each having a nucleus and a tail. For a while they moved away from their primary. In three weeks the nearer companion ceased to recede; it then expanded and finally disappeared. The fainter companion continued to recede until it had become, a month from discovery, brighter than the parent comet. In another month it began to approach its parent, its head swelling and becoming faint, the tail disappearing."

THE NATURE OF COMETS

It is probable that astronomers have learned more of the constitution and nature of comets from one small member of the Sun's family, than from all the other comets—periodic and non-periodic—put together. On February 27, 1826, Wilhelm von Biela, an amateur astronomer at Josephstadt, in Bohemia, detected a faint comet which was independently noticed ten days later by a French observer, Gambart, at Marseilles. When its orbit was calculated, it was found to be identical with those of comets which appeared in 1772 and 1805. The comet turned out to be a periodic one, revolving round the Sun in a period of between six and seven years. Its return was predicted for 1832, and, true to calculation, it reappeared in that year. Its reappearance was made the occasion of a "comet scare." Certain calculations were made which seemed to show that portions of the comet would sweep over part of the Earth's orbit. This statement gave rise to a dread lest the comet should strike the Earth and our world be destroyed. A panic ensued among the ignorant, especially in Paris, and the popular excitement was not cooled until the director of the Paris Observatory announced that the Earth and the comet would at no time approach within fifty million miles of each other. The comet was not seen in 1839, owing to its unfavourable position in the heavens, but on November 28, 1846, it was re-discovered. In less than a month it was seen to be pear-shaped, and on December 29 and early in January, it was found that the comet had actually separated into two distinct portions. All over the world astronomers observed the comet with amazement, for this was the first occasion within the memory of man on which a comet was seen to divide into two portions. The comet again returned in 1852. The

companion comet was again seen, but at a much greater distance. It was now a million and a quarter miles from its primary, eight times its distance in 1846. In 1859 the comet was not observed, but this was not considered remarkable, as it was in that year unfavourably placed for observation. However, much interest was displayed at its return in 1866, at which date it was expected to be very favourably placed. An active search was instituted, but neither Biela's Comet nor its little companion was seen. The comet was obviously lost, and astronomers gave up hope of ever seeing it again.

But an extraordinary thing happened. The comet was again due to appear in 1872. It was not visible, but when the Earth crossed its path, on the night of November 27, there was a magnificent shower of shooting stars. Beginning shortly after sunset, the "rain of fire," as one observer called the display, lasted until eleven o'clock. Four hundred meteors were counted in a minute and a half; and some magnificent fireballs equal in size to the apparent diameter of the Moon were observed. The Earth had not collided with Biela's comet, but it was ploughing its way through the wreckage and *débris* into which the comet had dissolved.

A German astronomer, Klinkerfues, observing at Göttingen, was impressed with the idea that Biela's Comet, or at least a portion of it, might still be visible, and concluded that if it were to be seen at all, it would be in the southern hemisphere, in the opposite region of the heavens from the point from which the meteors had radiated. Accordingly, convinced that the meteors represented the shattered *débris* of the comet, and believing that other portions of it might still be in existence, he telegraphed to Pogson, the astronomer at Madras, the

following message: "Biela touched Earth November 27, search near Theta Centauri." Pogson promptly turned his telescope to that portion of the sky, and glimpsed on December 2, and again on the following evening, a very faint object, which he at first took for Biela's Comet or its companion. It was shown, however, that it could not have been either, but was probably another fragment which was detached at an earlier date. The orbit of

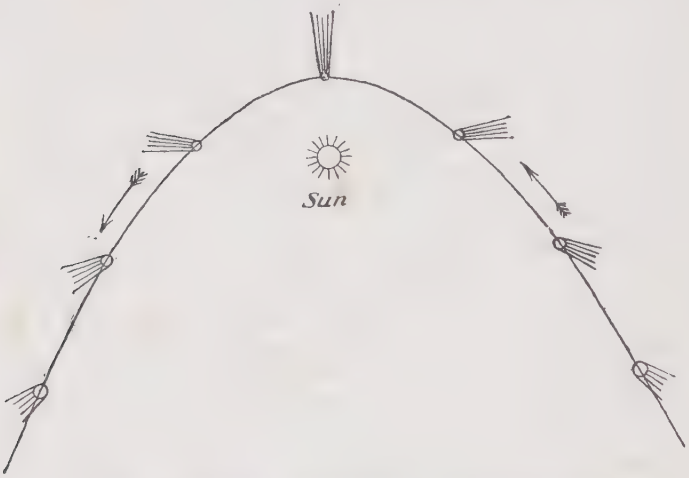


FIG. 5.—Showing how the Tail of a Comet is directed away from the Sun.

Biela's Comet was thus shown to be identical with the meteoric shower known as the Andromedids, and another fine shower was observed in 1885, when the Earth again crossed the path of the lost comet.

Biela's Comet therefore no longer exists; it has been dissolved into fragments; and with some of these fragments our planet collided on November 27, 1872, with the result that a display of celestial fireworks took place

which has seldom been surpassed. Thus we see that comets die, as Kepler said three centuries ago. Unlike the planets, they are not lasting, but break up into small particles of matter, which, when they enter our Earth's atmosphere, become ignited with the friction of the atmosphere and appear in the form of shooting stars.

To sum up, we know that comets are bodies of extreme tenuity. Stars are usually to be seen shining through them undimmed, and although they are of enormous bulk they have practically no weight. That is to say, they exercise no disturbing influences on the motions of the planets. In all these points comets differ from planets. And as already mentioned, there is another important point of difference. Although nothing in the changing Universe can be called eternal, the Sun and planets are certainly lasting bodies, but comets are not lasting. Even in the short period of man's life, comets have been seen to break up and disappear.

An admirable summary of our knowledge of comets is given by Mr. E. W. Maunder as follows :—"Though the bulk of comets is huge, they contain extraordinarily little substance. Their heads must contain some solid matter, but it is probably in the form of a loose aggregation of stones enveloped in vaporous material. There is some reason to suppose that comets are apt to shed some of these stones as they travel along their paths, for the orbits of the meteors that cause our greatest star showers are coincident with the paths of comets that have been observed. But it is not only by shedding its loose stones that a comet diminishes its bulk ; it also loses through its tail. As the comet gets close to the Sun, its head becomes heated and throws off concentric envelopes, much of which consists of matter in an extremely fine state of

division." Mr. Maunder goes on to show that for a particle of matter less than the one-twenty-five-thousandth part of an inch in diameter, the repulsive force of the Sun's light is greater than the attractive force of the central orb itself. "Particles in the outer envelope of the comet below this size will be driven away in a continuous stream, and will form that thin luminous fog which we see as the comet's tail."

Thus comets lose in bulk and mass through their heads and their tails. Of the subsequent history of the "luminous fog" driven off by the repelling power we know nothing, but of the loose stones shed by the head we know a great deal.

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